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Non-Conducting Coverings for Steam Pipes.

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Presented before the Society by
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EXPERIMENTS UPON NON-CONDUCTING COVERINGS FOR STEAM PIPES.

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INTRODUCTION.

In addition to the usual number of fires caused by steam-heating pipes, there have been several fires during the past year from the coverings of steam pipes.

An examination of the matter showed that neither dye-stuffs nor oils were present in these coverings, so that the fires could not be ascribed to spontaneous combustion.

There seemed to be very little accurate knowledge respecting the efficiency of steam-pipe coverings, although their general importance is universally acknowledged.

There was so much at stake in this matter that the underwriters in interest considered that it would be desirable to investigate the question of these non-conductors, both in respect to any possible dangers of combustion and also to the measure of their economic efficiency. The question was submitted to Professor Ordway, and, by the courtesy of Mr. Edward Atkinson, President of the Boston Manufacturers' Mutual Fire Insurance Company, I have the opportunity of presenting to you that portion of Professor Ordway's report, treating of the value of the coverings, with a description of the methods employed, and the results obtained. C. J. H. W.

In undertaking an investigation of steam-pipe coverings, it was necessary, in the first place, to decide what method, or methods, should be used for determining their efficiency as non-conductors of heat. I have met with no recorded experiments of which the details are given in full, but it seems that, in general, two modes have been employed heretofore. In one—the air chamber method—a portion of the covered pipe, while in use, is inclosed in a small box so as to form a close chamber into which the bulb of a thermometer is inserted. The inverse ratio of the temperatures indi-

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cated by the thermometer in different trials is supposed to show the relative excellence of the different coverings.

In the second, or condensation method, the steam is allowed to pass from the main pipe out into a side branch covered with the substance in question, and so arranged that whatever water is formed in an observed number of minutes may be drawn off from time to time and weighed or measured. The water is reckoned as having parted with as much latent heat as is contained in that weight of dry steam.

The air-chamber method it might be thought easy to carry out, but it is difficult to fit a box of any kind so closely to the covering that there will be no circulation of air into and out of the inclosed space. Of course, a lack of tightness will fatally vitiate the experiment. Again, a box surrounding the pipe and covering, presents a large radiating and cooling surface as compared with the covering itself; and there is no ready way of determining the amount of this continual radiation which increases with the temperature of the air within the chamber. There is no perfect non-conductor wherewith we can surround the air chamber, so as to confine therein all the heat received. If we could prevent all outward radiation, the cavity would, sooner or later, acquire the temperature of the steam in the pipe, and all coverings would finally give the same result. The only way to make useful observations would be to start with everything cold, and find the time required to raise the air in the chamber to a given temperature. This is, however, hardly practicable.

We cannot obtain absolute or quantitative results by this method, and the comparative figures require indeterminable corrections. Still it was thought advisable to try this plan among others, and see how far the results would correspond to those found by more definitive modes. Accordingly, the apparatus shown in Figs. 18 and 19 was devised and used for this purpose. Fig. 18 shows a transverse section of the whole apparatus as it was mounted, together with the covering and pipe. Fig. 19 represents one-half as seen from the side next the covering. In making the apparatus, pieces of white pine plank, *c*, are squared and rabbeted at the ends to receive the wooden braces, *f f*, which are firmly screwed on. A two-inch hole is bored from the inner side, two-thirds through, to form the cylindrical chamber *c*. The inner side is then planed out so that the concavity *s*, when properly lined, may exactly fit the convexity of the covering to be tried.

A hole, *x*, is bored from the top edge down into the chamber *c*. The concavity *s* and the chamber *c* are lined with thick woolen blanket, the large piece *d* being held in place by tacks *n n*.

The halves are clamped on the pipe-covering with the four iron rods *g*, and tightened to a close fit with the thumb nuts *h*. Thermometers, *t t*, are let down into the chambers, a little cotton wool being crowded in around the stems at *x*, to prevent the ingress of cold air.

The two chambers so applied serve to check each other; for if the thermometers differ much, there is a defect in the adjustment.

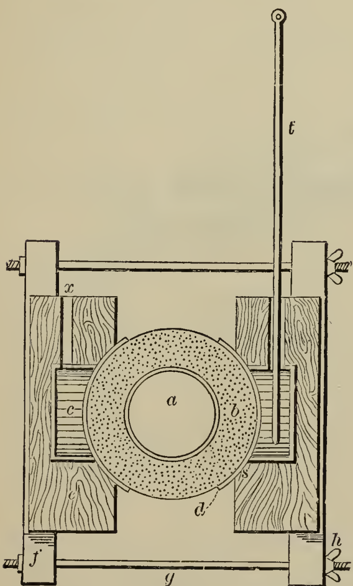


FIG. 18.

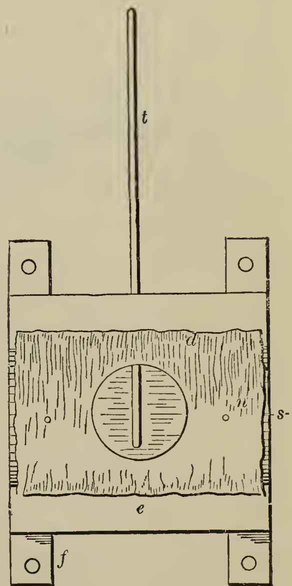


FIG. 19.

A difference of two or three degrees, however, may occur, on account of an inequality in the two sides of the covering itself.

The condensation method is indirect, and therefore a little uncertain. It necessarily assumes that the pipe is all the time filled with dry steam. But we can hardly expect to have pure steam when its generation is going on rapidly, and the vapor passes off through a long pipe which is all the time radiating heat. We can justly expect only a mixture of real steam with more or less mist. And if this mist, which has already lost its 500° C. [932° F.] of latent heat, is reckoned as invisible steam, our figures will not give the exact truth.

And then again, besides the two or three feet of pipe with the covering to be tried, there are necessarily the cap and other fittings which will lose heat in spite of any wrapping which we may put around them. The gross results, therefore, need to be corrected by the amount due to the condensation by that portion of the branch which is not protected by the covering. It is quite possible to find the amount of this correction, if one has the material of the covering so that he can apply it himself and make it uniform. Thus we may cover, say, three feet of pipe, wrap the fittings with a good non-conductor, and make trials enough to get a fair average. Then we may cut off one foot of the pipe and covering, keeping the other parts and their wrappings exactly the same as before, and make a second series of trials. Now, let x be the amount of condensed water due to the three feet of coating, and y that due to the fittings. Having found for one hour $x \times y = a$, by the first trials, and by the other set $\frac{2x}{3} \times y = b$; by combining these equations we get $x = 3(a\text{-}b)$; and $\frac{x}{3} = a\text{-}b =$ condensation per foot per hour.

If cutting the pipe is not feasible, the deduction to be made may presumably be ascertained in another way. First, determine the whole condensation by the covered pipe and the well wrapped fittings. Secondly, strip off the covering and try the naked pipe with the wrapped fittings. Thirdly, wrap the pipe just like the fittings, and make more trials. Lastly, strip off the wrappings from pipe and fittings and try all naked.

Now let $x =$ the amount of condensation by the naked pipe alone; $y =$ that by the naked fittings; $z =$ that by the wrapped pipe alone; $w =$ that by the wrapped fittings; and $u =$ that by the covering in question.

By the last determination above mentioned we have found $x + y = a$; by the second, $x + w = b$; by the first, $u + z = d$; and by the third, $z + w = c$. We may fairly assume that $x : y :: z : w$, or $xw = yz$. Then by the various eliminations and substitutions, we have:

$$x = \frac{a(b-c)}{a-c};\ y = \frac{a(a-b)}{a-c};\ w = \frac{(a-b)c}{a-c};\ z = \frac{(b-c)c}{a-c};$$

$$u = d - \frac{(b-c)c}{a-c}$$

In an actual trial, the result of which is given in No. 25 of the

appended table, the slag wool inclosed in straw board, supported by plaster rings at the ends, made altogether a covering 21 inches long. The extra pipe and the fittings were well wrapped with cotton wool, and the condensation was found $d = 108.6$ grams per hour. Removing the slag wool covering, it was found that $b = 344$ grams. Replacing the covering by cotton wool wrapping, it appeared that $c = 105.3$ grams. With all wrappings stripped off, it proved that $a = 428$ grams.

Hence, by substituting these values in the above formulas, we find $x = 316.7$; $y = 111.3$; $w = 27.3$; $z = 77.7$; $u = 81.3$. Then $\frac{12}{21} \times 81.3 = 46.5$ grams per foot per hour.

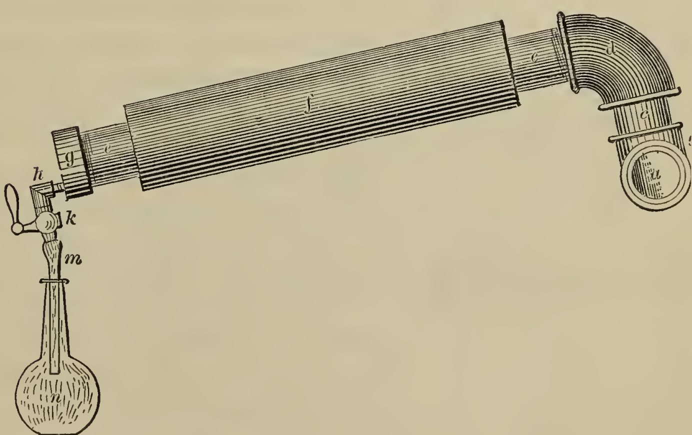


FIG. 20.

For making trials by condensation, I used the arrangement shown in side view in Fig. 20 : *a*, the main steam pipe; *b*, a T by means of which the steam may pass freely through the nipple *c* and the elbow *d* into the branch pipe *e* with its covering *f*. A bit of India-rubber tube *m*, attached to the stop cock *k*, connected with the cap *g*, allows the condensed water—when the cock is opened a little—to pass into the glass flask *n*, without direct exposure to air currents; *d*, *g*, *h*, and the uncovered parts of *e* are wrapped with cotton wool. The angle of inclination is such that whatever condenses in *d* and *c* runs back into the main pipe *a*, unless it remains suspended as mist, and is swept forward.

As to the question of mist, I see no way of settling it except by combining the condensation method, including the correction given above, with the calorimetric method now to be described.

The calorimetric method, besides being direct and absolute, seemed to me to promise a closer approximation to the truth than any plan used hitherto. To carry it out, the contrivance represented in Fig. 21 A and B, and Fig. 22 A and B, was provided of different sizes to suit different coverings.

Fig. 21 A shows a transverse section of the pipe, covering, and a pair of calorimeters. Fig. 21 B gives a longitudinal section through the line M N of 22 A. Fig. 22 A is an end view of the calorimeter. Fig. 22 B represents the same as seen from above.

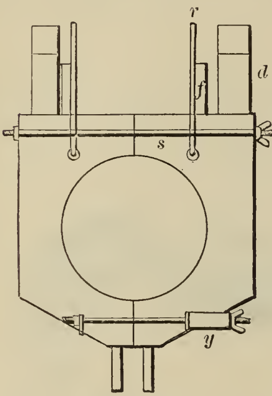


FIG. 21 A.

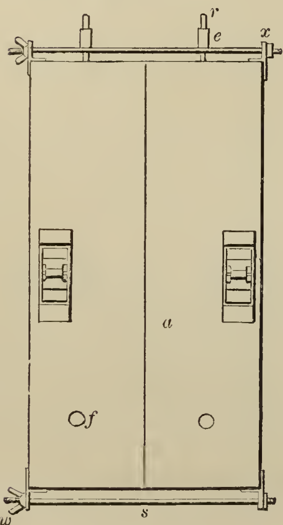
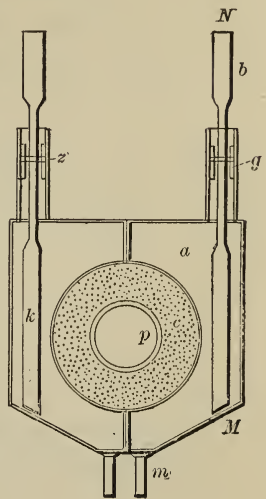


FIG. 21 B.

The calorimeters are made of sheet brass No. 29, and are so shaped that when clamped together they may completely and closely include a portion of the pipe covering *c*. The tube *f* serves for the introduction of water, and the subsequent insertion of the thermometer, which is retained in place by the perforated cork *h*. Another pipe in the bottom *m* serves for drawing off the water by removing the cork *n*. The glass tube *r* attached by a caoutchouc connector to a small brass tube in the end, shows the height of the water. The top piece *d*, to the inner sides of which are soldered slotted brass plates *g*, allows the wooden panel *v* to be swung back and forth on the brass pin *z*, to equalize the temperature of the water. The perforated brass ears *x* and the binding rods *s*, with the thumb nuts *w*, furnish the means of clamping the two halves over the pipe covering. Thick wooden washers *y* give a chance to turn the thumb nuts past the edge of the slanting bottom.

A different mode of clamping is shown in Figs. 23 and 24, the first being a view from above, and the other a side view. Here the pine wood braces *h*, held together by the bolts *r*, are distinct from

the calorimeters. This mode of clamping was actually used in most of the experiments, but the wooden braces were not so easy to manage, and they were much in the way of the wrapping. For in use the whole apparatus was covered with cotton batting put on thick and held on by cotton twine wound around in various directions. Cotton wool makes a good and cheap covering, but it takes much time to apply it. Latterly, it seemed best to try other wrappers, and for the sake of greater compactness the form shown in Figs. 25, 26, 27 was constructed. Here the long sheaths *z* receive the wooden rods *x*, which are held by pins at one end and the wooden wedges *w w* at the other. A calorimeter of this form was surrounded by a box of thin wood made much larger, so as to leave a space about 1½ inches thick all around the brass boxes—the pipes *c* and *f* and the top piece *p*, as well as the gauge *d*, projecting outside the wooden box. The space was filled with nearly two pounds of live geese feathers. The feathers make an



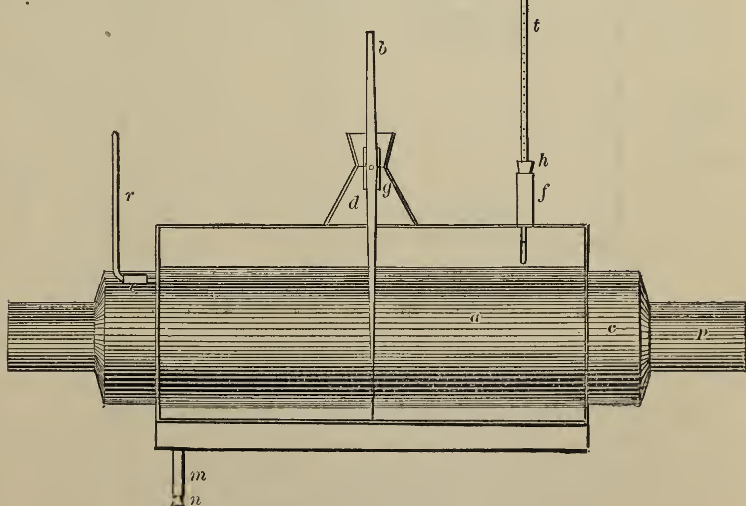


Fig. 22.—A & B.

excellent non-conductor, but they are rather expensive, and by no means easy to handle.

Then the clamping arrangement of Figs. 21 and 22 was tried, and a cover was made of three thicknesses of very soft woolen blanket sewed on; this is rather costly, but it is, perhaps, the best wrapper to use. A wrapper of hair-felt was tried twice, but it was too tender to be used many times, and it did not admit of sewing on, but had to be held on with twine wound around.

In making trials, the calorimeters are filled up with water 10° [50°F.], or 12°C. [53.6° F.] colder than the air of the room, the thermometers are inserted, and the water is well agitated with the paddles. The temperature of the water, the steam pipe, and the air of the room, and the time are noted down. Observations are made every half hour, or oftener, till the water stands 10° C. [50° F.], or 12° [53.6° F.] higher than the surrounding air. The water is then drawn off and weighed. The experiment is repeated times enough to give a fair average.

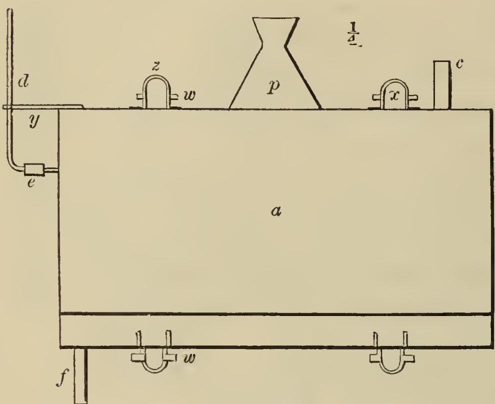


Fig. 23.

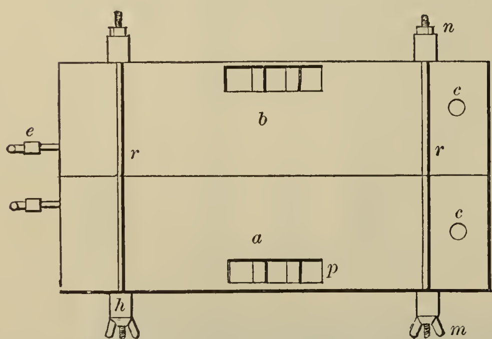


Fig. 24.

Of course, all the heat transmitted by the length of pipe covering inclosed by the apparatus is taken up by the water, and could be exactly determined were there no radiation from the calorimeter itself. But wrap as we may, there will still be a loss when the surrounding air is colder than the water. To neutralize the error from this source we should use only that part of the experiment which lies between two observations, in one of which the water is about as many degrees colder than the air as it is hotter in the other; thus the absorption of heat from without in the first part of the time is balanced by the radiation from within in the latter part.

The calorimeter itself takes up heat as well as the contained water, and we must therefore add to the weight of the water as much as corresponds to the weight of brass and immediate surroundings, the specific heat being taken into account. For every calorimeter, this is a constant quantity which may be determined

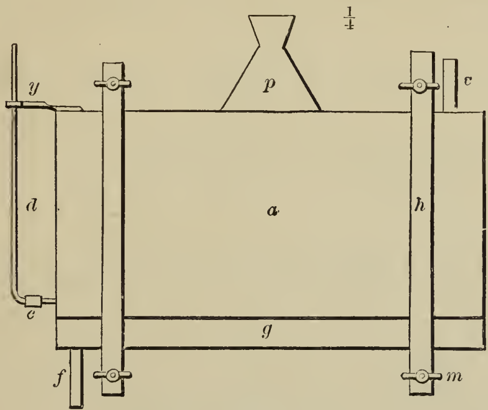


FIG. 25.

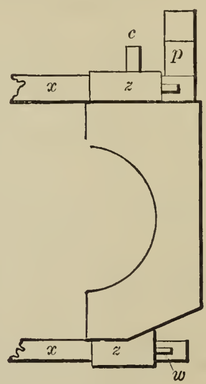


FIG. 26.

practically by mounting the apparatus on an unheated pipe, wrapping it as usual. Cold water is run in and allowed to stand some time, the temperature being noted. Then the water is as quickly as possible run out and replaced by warm water of known temperature. After a thorough agitation, the temperature is observed, and the warm water is drawn off and weighed.

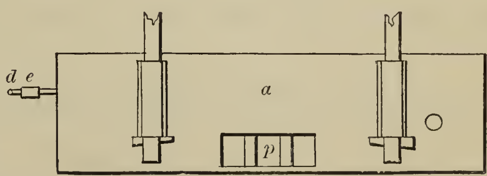


FIG. 27.

Let t = the temperature of the cold calorimeter.

t' = the temperature of the warm water at first.

T = the temperature of the warm water after it is run in, and a = the quantity of warm water drawn out and weighed.

If x = heat units taken up by the calorimeter, reckoned either in grains of water heated 1° C. or in pounds of water heated 1° F.; then

$$\mathrm{T} = \frac{a\,t' + t\,x}{a + x}; \text{ hence } x = \frac{a\,(t' - T)}{T - t}$$

In an actual trial, the water equivalent of the calorimeters *A I*, *A II* was found to be 194 grams for each.

In an experiment with covering No. 34 of the table hereto appended:

At 9h. 15m., *A I* stood at 12.63° C. [54.73° F.], and *A II* at 12.64° C. [54.75° F.]*

At 3h. 25m., *A I* stood at 42.73° C. [108.91° F.], and *A II* at 42.18° C. [107.92° F.].

Mean temperature of the air 27.7° C. [81.86° F.]

Interval, 370 minutes.

From *A I* were drawn off 3,260 grams of water; from *A II* 3,320 grams.

Calculating from these data:

$$(42.73-12.63)\ (3260+194)\times\frac{60}{370}=16.859^\circ \text{ C.}$$

$$(42.18-12.64)\ (3320+194)\times\frac{60}{370}=16.833^\circ \text{ C.}$$

The average of these and trials made on two other days was one kilogram of water heated 16.671° C. per hour in each calorimeter. But the two brass boxes include 14 inches in length of the covering.

Hence $\frac{12}{14}\times 2\times 16.671 = 28.579$ kilogram-centigrade heat units,

or one kilogram of water heated 28.579° C. per hour by each linear foot of the covering. To reduce this to pound-Fahrenheit heat units, we multiply by $\frac{9}{5}\times 2.205$, which gives 113.43° per foot per hour.

Thus we have an absolute measure of all the heat which is trans-

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*Though throughout this report many temperatures are expressed in degrees with two decimal places, it should be understood that these are not actual readings, but in most cases the observed numbers have been corrected according to the calibration table of each thermometer; and in calibrating, it was thought as well to carry out the calculations to hundredths of a degree.

mitted by the covering. But it may, with some reason, be objected that the rapidity of transmission, and therefore the amount of heat passing off from a constant source in a given time, is influenced by the temperature and nature of surrounding bodies; and hence that the communication of heat to a fixed quantity of water is not necessarily the same as that actually given off to air in free circulation. Further experiments are needed to determine exactly how the heat imparted to the water calorimeters compares with that given out to air by the freely exposed covering. We should naturally expect that as water has a higher specific heat than air it would induce a more rapid cooling, and that therefore the water calorimeter would give higher results than the condensation method. But we have a limited quantity of water allowed to get pretty warm as compared with an unlimited supply of cold air. In fact, the coverings No. 24 and No. 25 of the appended table were intended to be alike, and were very nearly so. As the temperature of the steam averaged 150° C. [302° F.] its latent heat was 500° C. [932° F.]. Now the quantity of water condensed per foot per hour in No. 25 was 46.5 grams. And $46.5 \times 500 \times \frac{1}{1000} = 23.250$ kilogram-centigrade heat units, while the calorimeter trial of No. 24 gave 22.807°. The difference is not large, and this tends to show that air-cooling and calorimeter cooling are not very unlike.

Any uncertainty as to whether water calorimeters show the actual loss of heat by pipe coverings does not affect their comparative indications respecting different coverings. A more important matter, perhaps, is the not unfrequent impossibility of exact fitting. Coverings which are plastered on are never of uniform thickness, nor are they exactly cylindrical. In such cases the contact of the calorimeters will be more or less imperfect, and radiation through confined air will be partly substituted for direct conduction. On the other hand, yielding coats, like hair felt, are somewhat compressed by clamping on the brass boxes, and yet more by the weight of the filled apparatus; and the more closely fibrous matter is compressed, the greater its transmitting power. So the results of the trials are likely to be somewhat too favorable to the hard and inelastic coverings.

In carrying out the examination of pipe coverings, it seemed best to get samples such that each one could be used for the three methods in succession. Accordingly, circulars were sent out requesting manufacturers and others interested in the subject to fur-

nish whatever specimens they wished to have submitted to competitive trial. The directions called for pieces of ordinary two-inch steam pipe two feet long, cut with a right-hand thread at each end, and then covered, in the usual way, for a length of eighteen inches between the threaded ends. In response to this invitation, thirty-one samples were sent in by various makers, and eight kinds were brought and applied directly to our hot steam pipe in place. In only one or two instances have prices been given.

The room available for the experiments is an iron-turning shop, through the upper part of which runs thirty-six feet of two-inch pipe, conveying to an engine steam of sixty pounds pressure. The engine is run, in term time, from 8.45 A.M. to 12 M., and from 1.30 to 4.30 P.M. During the noon hour the pipe is full of hot but not moving steam. Before entering the room, the pipe runs about 110 feet from the boiler. Two lengths of the pipe in the room were taken out and replaced by as many as possible of the two-foot sample pipes coupled together. Near the middle of a set was inserted a T with a three-quarters inch side connection turned upward. Into this was screwed a bushing furnished with a long thimble reaching nearly to the bottom of the T inside, as is shown in Fig. 28, in longitudinal section. *a* the T; *p* the plug; *n* the thimble, made of a piece of three-eighths inch gas pipe capped with *c* and filed thin. A thermometer *t* suspended in the thimble by means of the perforated cork *s* gives the temperature of the passing steam.

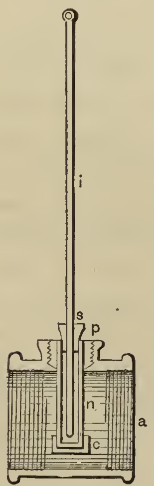

FIG. 28.

Calorimeter and air-chamber trials were made, with each covering two, three, or sometimes four successive days. When one set was gone through with, another set was mounted in their place. But several of the samples had been so covered as to leave too little space for a good grip of the pipe wrench, and therefore could not be dismounted in fit condition for connecting again as side branches. Moreover, the number of specimens sent in was unexpectedly large, some makers furnishing many pieces differing more in size than in kind. Hence it was necessary to be content with setting up again for the condensation trials only such uninjured pieces as might represent the different types of coverings.

When the experiments with each piece were finished, the cover, while still at its maximum of dryness, was stripped off, dissected, and weighed; for, of course, the non-conducting power is not the only thing to be considered. We must take into account the cost, weight, bulk, necessary thickness, durability, ease of application, ease of removal, repair and renewal, simplicity, appearance, freedom from smell, temptation to insects or mice, hardness, resistance to moisture, combustibility, liability to crack, and the possible chemical effect on the pipe.

Pipe coverings may be divided into four general classes:

1. Those consisting essentially of light fibrous matter, as hair, slag wool, or paper, applied immediately to the pipe.
2. Those composed of a paste or mortar, which is plastered directly on the pipe, in one or several coats.
3. Those having an air space next the pipe.
4. Complex combinations of different layers.

It will be seen that of all the coverings tried, as shown by the annexed table, the most efficient was simple hair felt with a cheap cover of burlap. It appears also, that of the whole number, seventeen owe their efficacy to hair.

Slag wool came third in rank; but it should be noticed that this was a most remarkable covering. The slag wool was two inches thick and was surrounded by wooden slats one inch thick, these being covered with three thicknesses of cloth. So the whole was enormously and absurdly bulky. On the other hand, this wool was not of commendable quality, for it parted with 38 per cent. of heavy globules when it was thrown on a sieve, and this superfluous portion had increased the weight without doing any good. A more feasible covering was tried in Nos. 24 and 25, with the very same fiber after shifting out the shotted slag. This one-inch coating showed a fair result, though, of course, by long heating and sifting and handling, the fiber had become much broken, and could not therefore be as efficient as new wool. It was desirable to try new slag wool of the best quality, but the dealers in the article were unwilling to sell a small quantity. No doubt the best kind would give a more favorable result than that shown in No. 24, and would prove really more economical than the cheap sort. I suppose this latter kind is the same substance that is known in England under the misleading name of "silicated cotton."

Spongy paper, as in No. 16, proves to be a tolerably good non-conductor. In a condensation experiment, not given in

the table, Reed's covering gave a net result of forty-six grams per foot per hour, which almost coincides with that of slag wool in No. 25.

Straw covered with cotton cloth, as in No. 28, does not show an encouraging degree of excellence.

The otherwise useless rice chaff of No. 18, moistened with water-glass to make it less inflammable and somewhat coherent, proved much more efficient than straw rope.

It should be remembered, fibrous or porous matter acts mainly by virtue of entrapped air, and hence the looser it is the better. Thus everybody knows that hard-spun woolen stuffs do not make warm clothing. Asbestos is commonly supposed to have wonderful virtue in resisting heat, but there is really no magic power in the mineral fiber. It is a non-conductor only when it is in a light, downy condition and full of air. The figures given in No. 50 show that hard-pressed asbestos paper conducts heat very readily. And it was observed that in those cases in which asbestos paper is put between the pipe and hair felt, the asbestos fails to prevent the scorching of the hair. Incombustibility should not be confounded with non-conducting power.

As to the second class, the plastered coverings, none seems to be worth much except the diatomaceous earth or "Fossil Meal," of Nos. 21, 26, and 27. Of only one or two of them was the exact composition known, but there is not one of such excellence that the secret of its composition is worth keeping. Most of the pastes have an admixture of hair, vegetable fiber, or asbestos to make them tougher and keep them from cracking. The more organic fibrous stuff which can be worked in the better, for it makes the covering lighter and looser, and hence less capable of transmitting heat. When such fibers are surrounded by clay, plaster, or other mineral matter, it makes little difference whether they are of themselves combustible or not; they cannot char or burn unless used in connection with steam of extremely high pressure, or superheated steam. So here again, as compared with animal or vegetable fibers, asbestos, which is really a heavy mineral, has more plausibility than positive virtue. Most of the makers of plastered coverings appear to have been experimenting with materials which are too dense.

To the third class, those with greater or less air space, belong Nos. 9, 12, 19, 20, 22, 23, 34, and 37.

With regard to the efficiency of coverings with an air space, the experiments so far are not decisive, because in no two trials was it

certain that the material was otherwise of precisely the same quality and thickness. In Nos. 34 and 36, which were apparently the same, with the exception of an additional wire gauze support in No. 34, the air space showed but a very slight advantage. The comparison of Nos. 16 and 19 is even unfavorable to the narrow air space.

But when there is no visible covering at all, as in Nos. 47, 48, and 51, it makes a wonderful difference whether the calorimeter comes in direct contact with the pipe, or a thin stratum of air intervenes. It seems, too, that a quarter of an inch of air is as good as an inch. This calls to mind the well-known fact that one may safely stay a few moments in the air of a room heated to a point much above the boiling-point of water, as in the old "hot room" of calico print works; but if the skin touches a metallic body or a liquid of the same temperature, burning or scalding ensues.

So it was also observed that when hair or paper remained for a considerable length of time in contact with the hot steam pipe the organic matter became browned or scorched, while the hair felt in No. 9 remained, to all appearances, entirely unchanged, except at the ends where it was gathered in and touched the pipe. It might be thought that the bright tin plate case, as such, had something to do with preventing the scorching; for, from the tradition of Leslie's old experiments on heat, a surface of bright tin is reputed to be a poor radiant and recipient. But when the mere tin case of No. 9 and the straw-board case of No. 20 were put on the pipe, side by side, the tin box soon became hotter than the hand could bear, while the straw-board could be handled.

An air space, then, may prove very useful in obviating one of the great objections to coverings of organic fibrous matter, though it is not specially beneficial in other respects. Woolly asbestos, or asbestos paper, which the makers of some of the specimens appear to have relied on for this purpose, does not accomplish the object, for in all those samples in which a wrapping of asbestos came between hair and the pipe, the hair, after the trials, was found to be discolored by the heat. And then again, experiments Nos. 47 and 50 show that a wrapping of asbestos paper does not insulate so well as the same thickness of mere air. The popular confidence in asbestos partakes of the character of a superstition.

Coverings of the fourth class, those made up of many layers of

different kinds, have not proved better or more efficient than the simpler ones; and we may justly set down much of the ingenuity shown in devising coverings of this class as fruitless. Of course, complexity enhances the cost, and there should be some corresponding advantage.

But of the actual prices charged, I have received statements in only one or two instances. It is evident, however, from the labor necessarily required to produce some of the specimens, that cheapness has not been kept sufficiently in mind. The question as to whether a covering shall be used or not is one mainly of dollars and cents, and the inquirer must be satisfied that the saving of heat will soon make up for the outlay.

From No. 51, it appears that a naked two-inch pipe, carrying sixty pounds steam, may condense 181 grams per foot per hour, and No. 25 shows that a cheap covering may reduce this to 46.5 grams, making a saving of 134.5 grams per hour, or 1.345 kilos.=2.96 lbs. of steam in a day of ten hours. So the covering of one hundred feet of pipe would save, in a year of 300 working days, coal enough to convert 88,800 lbs. of water into steam. If we consider one pound of coal as capable of making 8.88 lbs. of steam, we shall have a saving of five tons of coal per year for one hundred feet of the covering. So, where coal is worth $5 per ton, it would certainly be worth the while to use a covering costing not more than twelve cents per foot, but we might wish to think twice before taking one worth twenty-five cents per foot.

In some cases it may be worth the while to add a little to the expense for the sake of securing a good appearance and having a covering which can be easily kept clean. An encasement of cotton duck or canvas looks well, whether the cloth is drawn together by the edges and stitched, or is torn into narrow strips and wound around spirally. Except the costliness of this closely woven stuff, the only objection to such a jacket or bandage is its combustibility, and this ought to be obviated by painting the canvas with water-glass. Some of the plastered coverings sent in have a hard, smooth exterior finishing coat, which gives a pretty appearance, but adds too much to the already excessive weight.

The weight and bulk of a covering are of some consequence, for if we add to the pipe three or four times its weight or size of other matter, we make it troublesome to support. A coating over five inches in diameter for a two-inch pipe seems absurdly disproportionate; and as the pipe itself weighs fifty-six ounces per foot, an ad-

ditional weight of sixty ounces or more is altogether beyond reason. The weights given in the table show that some makers have sinned grievously in this matter. In the large and heavy specimens tried, excepting No. 3, there appears to be a lack of efficiency, and there is little else to commend them.

Of course, for every kind of covering there is an optimum of thickness beyond which the cost and bulk of any addition is not compensated by any further gain in efficiency, and this best size can be approximately determined only by a series of careful experiments with each particular substance or composition. As most of my trials have been of ready-made coverings furnished by others, there are few data for reasoning about the matter of thickness. In comparing Nos. 1 and 2, we see that an increase of hair, beyond an inch of thickness, or thirteen ounces of weight per foot, does very little good.

Nos. 27 and 35 were made with the same fossil meal paste, and put on by the same person ; and here we see that a much less thickness than one inch of fossil meal is insufficient.

Though Nos. 3 and 24 are not strictly comparable, the two taken together go to show that when poor slag wool is used it will pay to have it considerably more than an inch thick.

As to ease of application, repair or renewal, Reed's covering, Nos. 16 and 19, and the Chalmer-Spence Co.'s complex tubes, Nos. 6, 10, 12, and 17 stand foremost. These are molded into form and, partially bisected lengthwise—Reed's so as to leave merely a thickness of paper for a hinge, and the Chalmer-Spence through one side of the hollow cylinder—so that the tube has only to be opened or sprung apart somewhat, clasped over the pipe, and fastened together at the meeting edges with double-pointed tacks. The covering can be taken off at any time by taking out the tacks and prying the joints apart. Next to these comes hair felt which can be cut of suitable width, clasped around the pipe, and held on by winding string or fine wire around spirally. It may be left so, or cloth can be sewed on around it.

Straw rope can be wound around spirally at a pretty rapid rate, but in time it becomes so brittle that it is worthless when unwound again.

In No. 37, the tin plate cylinders are made in halves which lock together and are more easily put on than taken off. The inner case is held off from the steam pipe, to make an air space, by means of short corrugated tin plate rings.

The tin plate case of No. 9 is made in one-foot lengths, with two opposite longitudinal ribs projecting inward. Each length is made in halves, and the ribs are formed by turning in the edges so that they come double when the two halves are put together and fastened with solder.

The cylinders are so joined end to end that their ribs lie in planes at right angles to each other. Both this covering and No. 37 are lacking in simplicity and ease of adjustment.

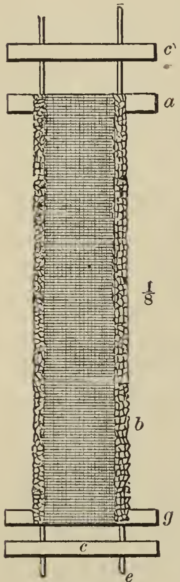

FIG. 29.

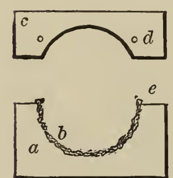

FIG. 30.

The air space in No. 19 is made in a ready way by winding around the pipe narrow strips of asbestos paper, some distance apart, before the covering is clamped on. In No. 12 the complex cylinder of hair and pasteboard is held off from the pipe by short, thick paper cylinders.

In No 20, the air space was made in a cheap and easy way with rings of plaster of Paris placed a foot apart, and a cylinder of straw board sprung on over them. This straw board had been shaped by rolling it in the machine with which tinkers form stove pipe, and was made large enough to have one edge lap over the other a little. The plaster rings were made in halves, with a groove around the outside to receive the string with which they were tied together on the pipe. Such rings can be cast with little trouble, and they should be well dried before using. They could be made of porous terra-cotta at trifling cost, and it would be better to fasten them on with small wire. The half rings in No. 22 were cut out of thin pine boards with a scroll saw, and the straw board was tacked to them ; but pine rings shrink and become scorched, while those of plaster or burned clay are hard, incombustible, and poor conductors of heat. The case of No. 24 was made in the same way, but with an incomplete cylinder of straw board, so that there was left, along the whole length of the upper side, a narrow aperture through which the slag wool was crowded in. The long aperture was closed over with a somewhat wider strip of straw board, the whole being finally held together by winding twine around.

The rice chaff of No. 18, the sphagnum of No. 22, and the charcoal of No. 29 were put on with the help of a wire cage specially contrived for the purpose. This is represented in Figs. 29 and 30. The wire gauze *b* is turned at the edges around the long wires *e*, and is tacked to the wooden supports *a*, *g*. The boards *c*, perforated with the holes *d*, are placed on the top of the pipe, the wire cradle is brought under, and the loose wires *e* are slipped through the holes *d*. A sufficiently wide piece of cotton cloth is laid in the cradle, and the hangers *c* are raised up with wedges till the cylindrical part of the gauze is parallel with the lower half of the circumference of the pipe. The filling is now crowded in around the bottom and sides of the pipe, and heaped over the top; the edges of the cloth are drawn together, basted, and then tightly sewed; the hangers are finally slipped off the ends of the wires, and the cradle is taken away to be moved on for making another length. With a little care the cloth edges may be drawn over so as to make the upper half of the covering cylindrical. The cotton cloth used was of the cheapest kind, costing about one cent for a foot of the covering. Of course, a cradle of sheet-iron or of wood could be used, but the wire gauze allows the free escape of any vapor that may be formed during the application of a moist filling to the hot pipe.

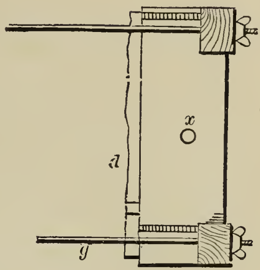

FIG. 31.

It requires some practice to put on paste coverings with a trowel, and it is by no means easy to get them uniform and round. With the exception of the fossil meal, the plastered coverings are worthless when they are taken off.

I have observed no chemical action by any of the coverings, except such as contain plaster of Paris, which, while wet, rusts iron rapidly. The corrosion of pipe, which is said to have occurred sometimes with slag wool which had become damp, must have been caused by the sulphate of lime formed by the oxidation of a trace of sulphide of calcium in the slag.

Respecting durability, little can be learned by trials lasting only a few weeks. But it is well known that animal and vegetable substances undergo a change by long-continued heating, and this sometimes becomes obvious even after a few days' exposure. Wool, hair, cotton, and paper in contact with a pipe at 150° C. [302·F.]

soon turn brown, and have their elasticity much impaired. To be sure, it is only a moderate thickness that becomes so affected, and samples of old coverings which have been sent me show that it takes years to scorch any considerable portion of the whole depth.

Straw suffers farther out than the poorer conductors. Specimen No. 39, which was said to have been in use nine years, was still bright and straw-like outside, but the steam pressure had been under fifteen pounds. The straw alone in this sample weighed 4.2 ounces per foot, while the new straw of No. 28 weighed 10.6 ounces. If No. 28 really represents the original dimensions and character of No. 39, as it was intended to, the impairment of efficiency by the shrinkage bears a strikingly small proportion to the loss of weight.

The change of organic matters by a steam heat is too slow to produce any sensible odor, but if by any chance hair felt gets wet while on the pipe, it gives out an unpleasant smell for a long time. I have known instances in which this proved so great an annoyance that the covering had to be stripped off; and the possibility of such an occurrence is no slight objection to the use of hair in immediate contact with the hot pipe. The intervention of an air space offers a possible prevention of this trouble as well as of the crisping of the hair.

As to the chances for spontaneous combustion of any covering consisting of vegetable fiber, it is difficult to pronounce with certainty. There is a report in circulation that a certain paper covering has taken fire of itself; but I believe this is rather a matter of interested surmise than of positive proof. I put two pieces of the indicted covering on a pipe near the boiler, where the temperature was very high outside and at least 150° C. [302° F.] within the pipe—one of the pieces as it came from the maker, the other charged with cotton-seed oil (this oil readily induces the combustion of cotton waste), and yet both the paper tubes remained so exposed to heat for six months without showing the slightest inclination to take fire.

Of course, coverings made of organic substances become excessively dry and tinder-like when they are constantly exposed for a long time to steam heat, and then they very readily catch fire when a spark or a flame touches them. Therefore, though there is little danger of fire from within, it is well to guard against fire from without. The impregnation of cloth wrappings with borax, tungstate of soda, or water-glass is calculated to lessen very much the danger from fire.

In connection with the testing of what were offered for fire-proof

window shutters some years ago, I was led to believe that one of the best and cheapest non-conductors could be made of water-glass and wood charcoal, since, by charring, all gas-forming material is eliminated from the wood, and carbon does not oxidize rapidly when covered with the varnish-like and fusible silicate. It was this mixture that I tried in No. 29; but as there was no light pine charcoal at hand I was obliged, by want of time for making some, to take a rather too dense substitute. Still, the result is encouraging, and I hope to follow up the matter farther, for this concreted uninflammable coal is capable of many useful applications.

The rice chaff in No. 18 was also mixed with enough water-glass to render it somewhat coherent when dry, and as the chaff is itself rather silicious, we thus get a covering so charged with mineral matter as to be hard to set on fire, and at the same time quite light and efficient as a non-conductor. Doubtless chopped straw might be used in the same way. But sawdust soaks up so much water-glass as to make a paste that dries too dense.

Coverings that contain flour or meal are liable to be troubled somewhat by mice. Even silicated rice chaff is not altogether proof against them. These animals also gnawed the interior of specimen No. 12.

When it is desirable to have a covering water-proof outside, this can be effected best by putting on a wrapper of sized cloth and applying to it one or two coats of oil paint. Of course, this should be done only after the covering has become perfectly dry. But trouble is sometimes caused from within, by leaking joints, and in such a case a water-proof coat only occasions a spreading of concealed mischief inside. On the other hand, a very porous coating allows the vaporized water to escape, and, if the leak is slight, no harm is done. It is well to use a pretty loose material for covering the joints, to separate those parts from the rest by impervious diaphragms of tin plate or plaster, and to make them so that they can be easily removed without disturbing the other portions.

The following table of specimens tried, Table I., is arranged in the order of their transmitting power as shown by the calorimetric method. The first column gives the source from which each of the samples was obtained, together with a concise description of the make-up, beginning with the coating next the pipe. Those marked "J. M. O." were home productions.

The maximum diameter is given in the second column, few being quite cylindrical.

The weight in the third column includes the average of the whole of the covering, but in many cases the essential part constitutes only a moderate portion of the whole weight. Fuller details of the structure are given in the second table.

The fourth column gives the highest temperature observed in the air chambers during the trials. In one or two instances the covering was so irregular that the air chambers could not be made to fit closely enough for a fair trial, and so no figure is given.

The numbers in the fifth column show the condensation by each foot of the covered pipe in one hour. "Gross" signifies that the condensation by the fittings and extra pipe is not allowed for, and the figures given are therefore really from one-fourth to one-third too high. The method given above for eliminating this error was not invented till most of the trials had been made. In the trials made latterly, the word "net" shows that the proper deduction has been made. It takes many days to get the data for the requisite correction, and it is hardly worth the while to spend the time for this, with many samples, till further careful experiments shall show whether the matter of mist really vitiates the results of the condensation method as much as we may suppose it can.

The sixth column shows how many heat units are actually transmitted in an hour by one foot in length of the pipe covering; that is, how many degrees Centigrade one kilogram of water may be heated by it, or how many kilograms of water may be raised 1° C.

In the last column the same loss of heat is expressed in degrees Fahrenheit which one pound avoirdupois of water may be heated.

As all the samples beyond No. 30 allow more than twice as much heat to pass through as is transmitted by No. 1, it would seem that in No. 31, and all after it, there is much room for improvement.

The average of the 46 coverings—No. 50 being left out—is 24.623 kilogram-centigrade heat units transmitted.

The average weight is 49 ounces, or a little over three pounds per foot.

TABLE I.

	Diameter of Covering.	Weight per Foot in Oz. Av.	Maximum Heat in Air Chambers.	Condensed 1 Ft., 1 Hour. in Grams.	Kilo. Cent. Heat Units 1 Ft., 1 Hour.	Pound-Fahr. Heat Units 1 Ft., 1 Hour.
No. 1. From Lowell Felting Mill—I. Hair felt, with single cover of burlap	5⅝ in.	21.4	53.98° C.	40.67 gross	12.842°	50.966°
No. 2. From Lowell Felting Mill—II. Hair felt, with single cover of burlap	4½	13.2	58.0	....	12.999	51.590
No. 3. Chalk & Lawton, Pawtucket, R. I.—II. Slag wool, wooden cage, burlap, cotton cloth, double	8	117.8	39.5	43.00 gross	14.465	57.408
No. 4. H. W. Johns' Non-conducting Covering—II. Asbestos fiber, asbestos paper, hair felt, asbestos paper, hair felt, asbestos paper, canvas	5⅜	29.3	47.88	....	14.498	57.539
No. 5. Greenwoods Co., New Hartford, Conn. Asbestos paper, hair felt, canvas	4½	17.3	61.8	....	15.074	59.705
No. 6. Chalmers-Spence Co., New York—II. Asbestos paper, hair, and pasteboard coiled together	4⅝	30.1	55.65	....	15.703	62.361
No. 7. Asbestos Packing Co.—III. Asbestos paper, double, hair felt, paper, canvas	4½	19.9	51.61	....	15.761	62.551
No. 8. Asbestos Packing Co.—II. Asbestos paper, hair felt, paper, canvas	5	18.4	53.46	41.00 gross	16.078	63.809
No. 9. Chalmers-Spence Co.—V. Air space, tin plate case, hair felt, canvas	4¾	20.8	57.0	....	17.122	67.952
No. 10. Chalmers-Spence Co.—I. Asbestos paper, hair, and pasteboard coiled together	4⅜	21.7	62.0	51.00 gross	17.551	69.255
No. 11. H. W. Johns' Non-conducting Covering—VI. Asbestos paper, hair felt, paper, canvas	4	17.2	61.9	....	17.801	70.647
No. 12. Chalmers-Spence Co.—IV. Air space, asbestos board, hair felt, asbestos paper, hair felt, pasteboard	6½	58.1	59.7	....	18.588	73.717

TABLE I.—(*Continued.*)

	DIAMETER OF COVERING.	WEIGHT PER FOOT IN OZ. AV.	MAXIMUM HEAT IN AIR CHAMBERS.	CONDENSED 1 FT., 1 HOUR. IN GRAMS.	KILO. CENT. HEAT UNITS 1 FT., 1 HOUR.	POUND-FAHR. HEAT UNITS 1 FT., 1 HOUR.
No. 13. H. W. JOHNS' Non-conducting Covering—I.						
Asbestos paper, asbestos paste, hair felt, asbestos board, hair felt, asbestos board, canvas	$7\frac{1}{4}$ in.	105.3	48.22° C.	....	19.291°	76.385°
No. 14. J. H. GRAHAM & SON, Boston—III.						
Clay, paper, hair felt, laths, plaster	5	52.9	....	....	19.423	77.085
No. 15. J. H. GRAHAM & SON—V.						
Asbestos paper, hair felt, paper, canvas	$4\frac{1}{2}$	16.1	65.0°	....	19.632	77.913
No. 16. REED'S Covering—I.						
Paper cylinder, joint covered with paper	$4\frac{3}{8}$	30.5	61.0	....	19.670	78.064
No. 17. CHALMERS-SPENCE CO.—III.						
Asbestos paper, hair and asbestos paper coiled together.	$4\frac{5}{8}$	30.3	53.5	....	20.129	79.886
No. 18. J. M. O.						
Silicated rice chaff, cotton cloth cover	$4\frac{3}{4}$	22.7	60.0	....	20.203	80.181
No. 19. REED'S Covering—II.						
Air space, asbestos paper, paper cylinder	$4\frac{3}{4}$	29.3	....	....	20.439	81.117
No. 20. J. M. O.						
Air space, straw board, hair felt, no cover	$4\frac{3}{4}$	12.0	....	....	20.693	82.124
No. 21. S. C. NIGHTINGALE & CHILDS—IV.						
Fossil meal and hair plastered on	$4\frac{3}{4}$	60.7	....	58.00 gross	21.151	83.940
No. 22. J. M. O.						
Air space, straw board, peat moss, cotton cloth	$4\frac{3}{4}$	10.6	....	....	21.631	85.848
No. 23. J. H. GRAHAM & SON—I.						
Air space, hair felt, laths, plaster	$5\frac{3}{8}$	63.1	54.4	....	21.820	86.596
No. 24. J. M. O.						
Slag wool, straw board	$4\frac{1}{4}$	24.1	....	....	22.807	90.510
No. 25. J. M. O.						
Slag wool, straw board	$4\frac{3}{8}$	24.8	....	46.50 net	....	....

No. 26. S. C. NIGHTINGALE & CHILDS—I.						
Fossil meal and hair plastered on........................	4¼	31.9	64.5	....	22.942	91.050
No. 27. S. C. NIGHTINGALE & CHILDS—II.						
Fossil meal and hair plastered on........................	4⅛	26.9	....	....	23.462	93.113
No. 28. W. E. PARKER, Pacific Mil's—I.						
Rye straw rope wound around, cotton cloth 4 ple	4½	20.2	64.8	55.00 gross	24.424	96.933
No. 29. J. M. O.						
Silicated hard wood, charcoal, cotton cloth cover.......	5	41.9	....	47.00 gross	24.650	97.830
No. 30. J. M. O.						
Carbon, plaster of Paris, flour, and hair plastered on...	4½	33.0	....	....	26.909	106.800
No. 31. ASBESTOS PACKING CO.—IV.						
Asbestos paste, clay and flax, paper pulp, mortar.......	5½	100.1	63.0	....	27.411	108.78
No. 32. J. M. O.						
Dry rice chaff, straw board................................	3¾	8.4	....	....	27.607	109.56
No. 33. J. H. GRAHAM & SON—IV.						
Asbestos and clay, laths, paper, mortar.................	5	58.0	66.0	....	28.159	111.75
No. 34. CHALMERS-SPENCE CO., "Pat. Air Space."						
Half-inch air space, wire netting, asbestos paste.......	5	41.0	72.8	74.00 gross	28.579	113.43
No. 35. S. C. NIGHTINGALE & CHILDS—III.						
Fossil meal and hair..	3¼	17.1	....	....	28.882	114.62
No. 36. CHALMERS-SPENCE CO., "Solid Covering."						
Asbestos paste..	4½	34.4	74.2	61.00 gross	29.599	117.47
No. 37. CHALK & LAWTON—II.						
Air space, tin-plate case, asbestos paper, tin-plate case..	4	29.0	52.14	....	29.660	117.71
No. 38. EUREKA COVERING CO., Fitchburg, Mass.						
Meal, clay and hair, meal, clay, sawdust, flax fiber.....	5¼	81.9	70.0	79.00 gross	30.171	119.74
No. 39. W. E. PARKER, Pacific Mills—II.						
Rye straw-rope, cotton cloth, 6 ple. (after nine years' use)	4¼	9.8	70.8	....	30.286	120.20
No. 40. ASBESTOS PACKING CO.—I.						
Asbestos paper, plaster and flax fiber	5⅞	111.5	73.8	....	31.267	124.09
No. 41. J. H. GRAHAM & SON—II.						
Plaster paste	5	67.5	79.8	....	33.477	132.86
No. 42. SAMUEL TAYLOR'S Non-conducting Composition.						
Clay and short fibrous matter..............................	5¼	94.1	77.3	....	36.782	145.98
No. 43. H. W. JOHNS' Non-conducting Covering—IV.						
Asbestos paper, asbestos paste...........................	6¼	201.8	69.2	....	37.951	150.61
No. 44. J. M. O.						
Anthracite ashes, plaster of Paris, flour, hair..........	4¾	79.2	....	....	39.159	155.41

TABLE I.—(*Continued.*)

	DIAMETER OF COVERING.	WEIGHT PER FOOT IN OZ. AV.	MAXIMUM HEAT IN AIR CHAMBERS.	CONDENSED 1 FT., 1 HOUR, IN GRAMS.	KILO.-CENT. HEAT UNITS 1 FT., 1 HOUR.	POUND-FAHR. HEAT UNITS 1 FT., 1 HOUR.
No. 45. H. W. JOHNS' Non-conducting Covering—V. Asbestos paper, asbestos paste	$6\frac{1}{2}$	171.2	70.0°	....	41.079°	163.03°
No. 46. H. W. JOHNS' Non-Conducting Covering—III. Asbestos paper, asbestos paper	$5\frac{1}{4}$	99.8	77.8	87.00 gross	43.097	171.04
No. 47. J. M. O. Mere air space	$2\frac{15}{16}$	....	....	....	49.241	195.42
No. 48. J. M. O. Mere air space	$4\frac{3}{4}$	....	....	....	50.405	200.04
No. 49. FALL RIVER STEAM PIPE COVERING CO. Clay and refuse of vegetable fiber	$4\frac{1}{4}$	65.2	91.8	....	51.727	205.29
No. 50. J. M. O. Asbestos paper wound round four times	$2\frac{7}{8}$	....	....	....	56.371	223.72
No. 51. J. M. O. Naked pipe	$2\frac{1}{32}$	....	....	181.00 net	391.830	1555.10

TABLE II.

No. 1. Hair felt, 826 grams; burlap and twine, 85g. Length 18 in.

No. 2. Hair felt, 493g.; burlap, 50g.; twine, 17g. Length, 18 in.

No. 3. Slag wool, 2 in. thick, 3,860g.; wooden slats, ¾ in. thick, and nails, 1,815g.; wooden rings at ends, 1⅝ in. thick, 540g.; tin-plate rings between wooden rings and pipe, 51g.; burlap, 127g.; cotton cloth two thicknesses, and paint, 270g.; tacks, 13g. Length, 24 in.

No. 4. Asbestos paper faced with loose asbestos fibre, 16½ × 25 in., 205g.; ¾ in. hair felt, 18 × 10½ in., 282 g.; twine, 3g; asbestos paper, 17½ × 18 in.; 112g.; ¾ in. hair felt, 17½ × 14 in., 407g.; twine, asbestos paper, 17½ × 16, 133g.; canvas 19 by 18 in., 80g. Length, 17½ in.

No. 5. Asbestos paper, 119g.; twine, 4g.; hair felt, 458g.; canvas, 94g. Length, 16½ in.

No. 6. Hair and pasteboard, not easily separated. Whole weight, 1,280g. Length, 18 in.

No. 7. Asbestos paper doubled, 110g.; hair felt, 486g.; paper, 157g.; canvas and string, 93g. Length, 18 in.

No. 8. Asbestos paper, two thicknesses, 98g.; hair felt, 1¼ in. thick, 16½ in. wide, 16½ × 12 in., 456g.; twine, 6g.; paper, 17¾ × 31½ in., 156g.; canvas, 87g. Length, 17½ in.

No. 9. Tin-plate case and ribs, 580g.; 1 in. hair felt, 494g.; canvas and twine, 94g. Length. 23 in.

No. 10. Hair and pasteboard cemented together. Whole weight, 910g. Length, 17¾ in.

No. 11. Asbestos paper, three thicknesses, 172g.; twine, 6g; 1 in. hair felt, 552g.; twine, 23g.; paper, 123g.; canvas, 81g. Length, 23½ in.

No. 12. End pieces of paper, 3 in. long, lined with asbestos paper, 575g.; asbestos paper, hair felt and pasteboard cemented together, 1,860g. Length, 17¾ in.

No. 13. Asbestos paper, two thicknesses, 167g.; asbestos paste, 1 in. thick, 2,910g.; ⅝ in. hair felt, 385g.; twine, 5g.; asbestos board 220g.; ⅝ in. hair felt, 505g.; twine, 6g.; asbestos board, 301g.; canvas, 107g. Length, 18½ in.

No. 14. Clay, 760g.; paper, 115g.; hair felt, 280g.; laths, 430g.; iron wire and plaster, 2,270g. Length, 29 in.

No. 15. Asbestos paper, several thicknesses, 299g.; hair felt, 425g.; twine, 2g.; paper, 198g.; canvas, 137g. Length, 28 in.

No. 16. Alike throughout, 1,280g. Length, 17¾ in.

No. 17. Hair and asbestos cemented together, 1,290g. Length, 18 in.

No. 18. Silicated rice chaff, 1,060g.; wooden rings and cloth wrapper, 120g. Length, 22 in.

No. 19. Asbestos paper rings, paper tube, whole weight, 1,230g. Length, 17¾ in.

No. 20. Wooden rings and straw board, 249g.; hair felt and twine, 443g. Length, 24½ in.

No. 21. Fossil meal and hair, alike throughout, 2,940g. Length, 20½ in.

No. 22. Wooden rings, 87g.; straw board, 192g.; tacks, 5g.; outer rings of paper, 1¼ in. wide, 113g.; sphagnum, 174g.; cloth, 40g. Length, 24½ in.

No. 23. Two iron rings, 1 in. wide, and tacks, 440g.; ⅝ in. hair felt, 218g.; laths, 351g.; wire and plaster, 2,350g. Length, 21½ in.

No. 24. Gypsum rings, 256g.; straw board cover, 201g.; slag-wood filling, 940g. Length, 24½ in.

No. 25. Plaster ends, 253g.; straw board, 175g.; slag-wool filling, 802g. Length, 21 in.

No. 26. Hair and fossil meal, uniform throughout, 980g. Length, 13 in.

No. 27. Fossil meal and hair, uniform throughout, 1,270g. Length, 20 in.

No. 28. Straw rope, 1 in. thick, 400g.; cotton cloth, four thicknesses, 400g.; iron rings at the ends, not included in the weight given in Table 1. Length, 16 in.

No. 29. Silicated charcoal, 1,760g.; wooden rings and cloth wrapper, 120g. Length, 19 in.

No. 30. Paste of plaster, carbon, flour and hair, 1,560g. Length, 20 in.

No. 31. Asbestos paste, 820g.; clay and fibre, 960g.; paper pulp, 1,560g.; twine, 23g.; mortar, 3,260g. Length, 42 in.

No. 32. Wooden rings, 74g.; straw board, 166g.; tacks, 5g.; rice chaff filling, 240g. Length, 24½ in.

No. 33. Asbestos and clay, 580g.; wood and wire, 325g.; paper, 332g.; plastering, 2,052g. Length, 24 in.

No. 34. Wire netting and sheet-iron props, 210g.; asbestos paste, 1,340g. Length, 16 in.

No. 35. Fossil meal and hair, uniform throughout, 770g. Length, 19 in.

No. 36. Asbestos paste, uniform throughout, 1,300g. Length, 16 in.

No. 37. Corrugated rings of tin-plate, 97g.; tin-plate cylinder, 345g.; asbestos paper, 204g.; tin-plate cylinder, 445g.; tin-plate ends, 80g. Length, 16¾ in.

No. 38. Two kinds of paste not separated, 3,290g. Length, 17 in.

No. 39. Straw rope, 160g.; six thicknesses cotton cloth, 212g.; iron rings at ends not reckoned. Length, 16 in.

No. 40. Asbestos paper, 179g.; three coats plaster with fibre, 4,430g. Length, 17½ in.

No. 41. Paste, uniform throughout, 5,740g. Length, 36 in.

No. 42. Clay and fiber, uniform throughout, 3,500g. Length, 15¾ in.

No. 43. Asbestos paper and twine, 102g.; asbestos paste, 8,760g. Length, 18½ in.

No. 44. Ashes, plaster, flour and hair, uniform throughout, 3,740g. Length, 20 in.

No. 45. Asbestos paper, 113g.; asbestos paste, 7,370g. Length, 18½ in.

No. 46. Asbestos paper, asbestos paste, together, 4,320g. Length, 18½ in.

No. 47. Clay and fiber, alike throughout, 2,310g. Length, 15 in.

INDEX TO TABLE I.

Air space, Nos. 9, 12, 19, 20, 22, 23, 34, 37, 47, 48.
Asbestos Packing Co., Nos. 7, 8, 31, 403.
Asbestos paper, No. 50.

Chalk & Lawton, Nos. 3, 37.
Chalmers Spence Co., Nos. 6, 9, 10, 12, 17, 34, 36.
Charcoal, No. 29.
Complex, Nos. 3, 4, 6, 7, 8, 10, 11, 12, 13, 14, 17, 22, 33.
Eureka Covering Co., No. 38.
Fall River Steam Covering Co., No. 49.
Fossil meal, Nos. 21, 26, 27, 35.
J. H. Graham & Son, Nos. 14, 23, 33, 41.
Greenwood Co., No. 5.
Hair felt, Nos. 1, 2, 5, 20.
H. W. Johns' non-conducting covering, Nos. 4, 11, 13, 43, 45, 46.
Lowell Felting Mill, Nos. 1, 2.
Naked pipe, No. 51.
S. C. Nightingale & Childs, Nos. 21, 26, 27, 35.
J. M. O., Nos. 18, 20, 22, 24, 25, 29, 30, 32, 44, 47, 48, 50, 51.
W. E. Parker, Nos. 28, 39.
Pastes, Nos. 30, 31, 36, 38, 40, 41, 42, 43, 44, 45, 46, 49.
Reed's covering, Nos. 16, 19.
Rice chaff, Nos, 18, 32.
Slag wool, Nos. 3, 24, 25.
Straw, Nos. 28, 39.
Samuel Taylor's non-conducting composition, No. 42.

CXLV.*

NON-CONDUCTING COVERINGS FOR STEAM-PIPES.

Further Experiments.

BY PROF. JOHN M. ORDWAY, BOSTON, MASS. PRESENTED BY C. J. H. WOODBURY, BOSTON, MASS.

[*Second Paper.*] †

In making the trial of steam-pipe coverings described in the former paper, the only place available was a room occupied with machinery; and as the steam-pipe could not be extended or changed in place, some desirable arrangements could not be carried out. The removal of the machinery and the enlargement of the room at length gave a chance to mount pipes for the special purpose of making further experiments. A connection was made with the main pipe conveying the steam of three boilers in which the pressure is maintained at about 65 lbs. A valve admits the steam to a short horizontal two-inch pipe provided with a pocket to receive whatever water may come forward. An elbow above the pocket conveys the steam into a slightly inclined two-inch pipe, also provided with a pocket, from which the water condensed in this two-foot length of pipe can be drawn off as it accumulates. The steam passes upward and through an elbow to a thirty-foot length of two-inch pipe, likewise provided with a pocket, and thence into a horizontal pipe with some side connections, and through a smaller descending pipe into a trap connected with the return pipe. The side connections are inclined two-inch pipes, 2½, 5, and 10 feet long, capped at the outer ends, the caps being provided with small stop-cocks for drawing off the condensed water. It is thus made possible to determine the condensation in two feet and thirty feet of transmitting pipe, and in 2½, 5, and 10 feet of blind pipes simply receiving steam. It had been a question whether condensation would be proportionally the same in long blind pipes as in short ones. It is conceivable that with very long pipes of small diameter there might be a difference. But it is found that ten feet of two-inch pipe condenses very nearly four times as much as 2½ feet.

The determinable condensation in the transmitting pipes has been

* Presented at the Pittsburgh meeting (May, 1884) of the American Society of Mechanical Engineers, and forming part of Volume V. of the *Transactions.*

† See page 73 of present volume.

found anomalous, and by no means proportionate to the lengths. I have been much puzzled to account for the strange behavior of these pipes, and have even gone so far as to change the arrangement. But the irregularity still continues. It is evident that the water formed does not all find its way into the proper pockets, and that moving steam must sometimes carry forward not a little mist.

Before placing much reliance on the results obtained in the way of condensation, it is proper to ascertain the quality of the steam at various times. For this purpose small cocks were screwed into the fittings in three places, and to them there were attached spiral coils of brass tube of $\frac{1}{12}$ inch bore, open at the end. Each of the coils is inclosed in a calorimeter of about twelve litres capacity. A weighed quantity of cold water is introduced into the calorimeter, and the steam is allowed to blow in for some three minutes. From the temperature of the steam and the increase of the water in weight and temperature we may easily calculate the percentage of mist in the steam. In many trials the steam has been found to be dry, while in others the proportion of mist ranges from two or three up to forty-two per cent. of the whole. This "priming" of the steam comes unexpectedly, and may last but a short time; but even a short continuance is sufficient to vitiate any determinations of lost heat based on the latent heat of the supposed steam. As there is no instrument which, like the thermometer, renders variations visible, changes may come and go unsuspected and unknown.

There is another source of inaccuracy in trials by the condensation method. The water must be drawn off frequently, and let off while it is far above 100° C. Consequently, much of it changes into vapor and escapes. I have endeavored to obviate this difficulty as far as possible by letting out the boiling water slowly, and running it through a long, twice-bent glass tube into a flask. But the precautions are by no means perfectly effectual. Any more complicated apparatus for drawing off the water would add a mass of cooling metal which would of itself be a source of error.

It was desirable to try the relation between the condensation which occurs when the heat is transmitted to the air and that which takes place when the covering is surrounded by water. Having a blind pipe thirty inches long, a new calorimeter was made twenty-eight inches long,—not in halves to be clamped together, but whole, to be slipped over the end of the pipe. With this arrangement it is possible to determine the whole condensation of the

pipe when the calorimeter surrounds it, and then again when the transmitted heat goes into the air. The trials with this apparatus have not been so numerous as I could have wished, but they go to show that the radiation into air and that into water are very nearly the same.

Being confirmed in my belief of the greater reliability of the calorimetric mode of testing, I have tried several coverings of substances not used in the former trials, or used in a different way. Among others, one covering of cork was tried, as it was furnished by the "Société Anonyme des Liéges appliqués à l'Industrie," of Paris. This covering consists of long strips of cork with the edges nicely beveled, so that when they are laid side by side around the pipe they make an accurately fitting hollow prism, touching the pipe along the median line of each inner side. In the case of a two-inch pipe, ten strips are furnished. These are first tied on temporarily till the cork is well dried, and they are then bound on firmly, with tinned iron wire. Such a covering is neat and strong, easy to put on and easy to take off. It is particularly suitable for pipes or boilers which are subject to concussions or jarring, like locomotive boilers. Cork is a good non-conductor, but the specimen sent me was too thin, being only five-eighths of an inch in thickness. An average of five trials showed a transmission of 26.54 kilogram centigrade heat units per foot per hour. Much better results were shown by a thicker covering of cork chips coated and cemented together with waterglass. This makes an admirable covering,—one of the best ever devised.

It is difficult to apply a perfectly uniform and definite thickness of any covering to a round pipe, nor is it easy to impart a precise degree of compression to a cylindrical covering. Therefore, a new apparatus was set up for experiments with exact thicknesses and densities. A short piece of six-inch steam-pipe was provided with a malleable iron cap at each end, one of the caps being turned to a true face. The other cap was furnished with one pipe for introducing steam and another to carry off water and excess of steam. The turned cap is 7½ inches in diameter. A canteen-like calorimeter of brass, six inches in diameter, can be adjusted with its face at any desired distance from the turned cap. The vacant interval may be surrounded with a strip of pasteboard cemented to the cylindrical sides of the cap, so as to make a round box with a narrow opening on the upper side. Through this opening any substance in powder may be introduced, and either left loose or rammed in.

This apparatus has enabled me to try the transmissive power of various powders and fibrous subtances under various degrees of compression.

The following list gives the kilogram-centigrade heat units transmitted per hour through a thickness of twenty-five millimeters:—

Fine table salt	36	Magnesia alba, compressed	7
Plumbago	35	Magnesia alba, loose	6.7
Fine washed sand	30.7	Pine Charcoal	6.8
Coarse washed sand	30.6	Calcined Magnesia	6.2
Fibrous Asbestos	24.2	Cork Charcoal, coarse	6.2
Air alone	23.7	Cork Charcoal, fine	5.9
Anthracite Coal	17.6	Live geese feathers, loose	5.8
Finest sand	15.7	Live geese feathers, compressed	4.8
Flour of Pumice-stone	15.4	Cotton, loose	5.4
Plaster of Paris	15.3	Cotton, compressed	4.5
Sulphate of Barium	13.2	Wool, loose	5.3
Paris White	10.2	Wool, compressed	4
Zinc White	8.5	Wool, compressed more	4.5
Fossil Meal, compressed	7.7	Lampblack	4.8
Fossil Meal, loose	7.2		

Peclet speaks of cotton and other filamentous substances, as having the same transmissive power, whatever may be the degree of compression,—"quelle que soit sa densité." And this seems to be approximately correct for moderate degrees of crowding, but it is by no means exact. Moderate condensation somewhat enhances the non-conductive power, because it more fully prevents any motion of the entrapped air, and hence any convection. But we soon arrive at a point beyond which farther compactness does no good.

It is interesting to observe that at the temperature of 155° C. a mere air space is of little service. Probably the greater the heat the greater is the need of something to prevent the lively motion of the air. Were the arrangement such that the heater was horizontal, the air space below the level face, and the calorimeter at bottom, of course the result would be very different, for then convection would have no influence. But in any practical use of air spaces such an arrangement is rarely possible. Unarrested air cannot be ranked among the best of non-conductors. Mere air spaces are not to be recommended, except when light is to be admitted while heat is retained, as in the case of double windows.

[NOTE —The necessary stoppage of the steam circulation in the buildings where these experiments are made has compelled the author to defer several further investigations to a future paper, but these memoranda are given as they stand to supplement some details of the previous notes.].

CLXIV.*

NON-CONDUCTING COVERINGS FOR STEAM PIPES.

Conclusion.†

BY PROF. JOHN M. ORDWAY. PRESENTED BY C. J. H. WOODBURY, BOSTON, MASS.

INTRODUCTION.

This paper forms the conclusion of the investigations made for the Factory Mutual Insurance Companies upon non-conductors for steam pipes, and contains experiments upon the relative value of methods suggested in the course of the discussion upon this subject at the last annual meeting of this Society. This supplementary work was undertaken in order to decide by actual experiment whether the value of a non-conductor can be determined in a more accurate manner by an actual calorimetric measurement of the heat radiated from a protected pipe containing steam in active circulation, as is generally the case where such protection is used; or whether the desired facts could be obtained by the usual method, estimating the loss by radiation on the assumption that it was represented by the thermal equivalent of the water entrained in a pipe of quiescent steam. The comparative results have in every particular given the preference to the method originally used in this work, of measuring the actual loss by radiation by means of calorimeters fitting around the pipe covering.

In carrying out this second series of experiments, measurements have also been made of the radiation from envelopes of numerous materials which have been suggested since the former paper was read. In this connection it must be emphasized that the use of combustible organic material is not recommended for steam pipe coverings unless protected against fire by water-glass, or some equivalent material which is both non-combustible and adhesive.

C. J. H. W.

The experiments, of which an account is given in the former report, were limited mostly to samples of pipe coverings sent in by different manufacturers. It had been hoped that many other trials

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* Presented at the New York Meeting (November, 1884) of the American Society of Mechanical Engineers and forming part of Volume VI. of the Transactions.

† See Vol. V. Transactions A. S. M. E., pp. 73 and 212.

might be made, but steam could be had only a few days after the middle of May, and the building was altered during the following half year, so that the work could not be resumed till winter. At length the machinery was removed, the room was extended, and

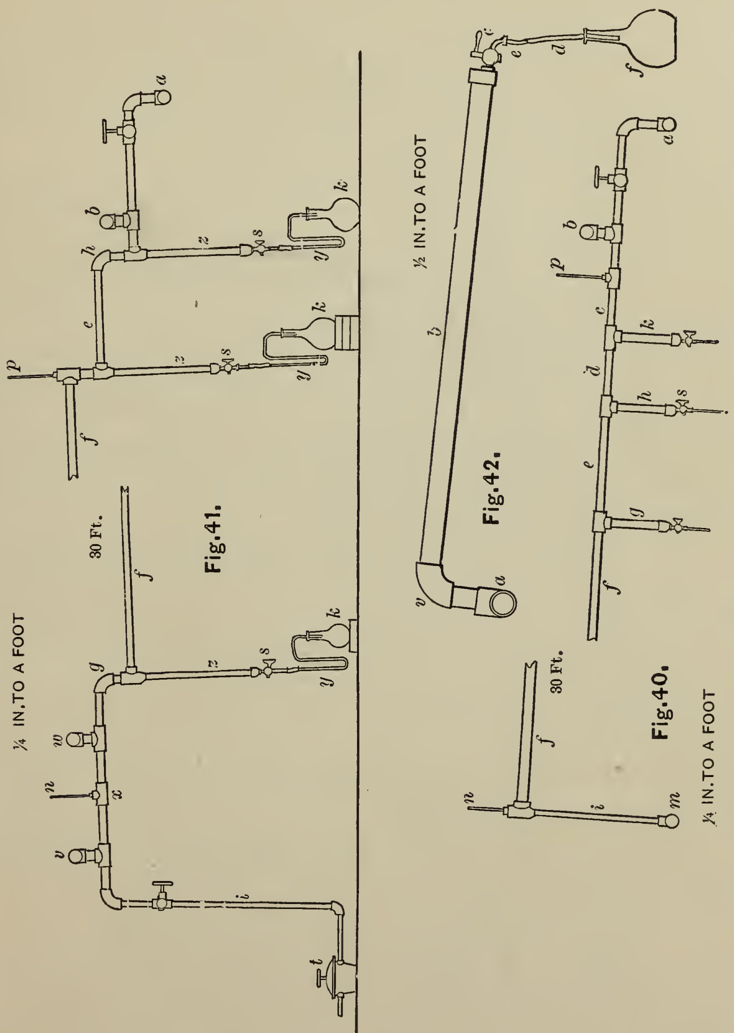

Fig. 41.

Fig. 42.

Fig. 40.

special apparatus was fitted up for continuing the investigation. The steam was now taken from a large pipe connected with three boilers about one hundred feet away.

To make experiments on condensation, a two-inch pipe was set

at a convenient height, with an upward slope of about four degrees, as shown in Fig. 40. Three branches, *g*, *h*, *k*, directed downwards, served respectively to receive the returning water from the 1, 2 and 30 foot lengths *d*, *e*, *f*. To the elbow *b* was connected a blind pipe 30 inches long, similar to the one shown in Fig. 42. The steam, after traversing the 2-inch pipe, passed downwards through the pipe *i* and entered the general circulation of the building at *m*. A valve interposed between *i* and *m* is not shown in the drawing. Thermometers *n* and *p* showed the temperature of the steam, which was generally about 155° C. = 311° F.

The heat within the pipe being so high, of course the condensed water was overheated and could not be drawn off, from time to time, without some loss by boiling and vaporization during its escape. This is a trouble which necessarily occurs in all experiments by condensation, and I was unable to devise any way in which the error could be wholly avoided. It was lessened as much as possible by drawing the water very slowly through a double siphon of glass tube, of $\frac{1}{8}$ inch bore, into a glass flask. This arrangement is shown in Fig. 41 at *y*, *k*. A small brass tube would answer as well, for one can tell when the water is all out by a sudden change in the rushing sound.

It is also difficult to get stop-cocks which are tight enough and will continue so for any length of time. It was expected that whatever water came forward with the steam would be intercepted by the pocket *k*, and that therefore what collected in *h* would be due to the condensation by *e*, and what was drawn off from *g* would show the amount condensed by *f*. But these reasonable anticipations were not realized. In fact, on trial of the naked pipe, the condensation by the two-foot piece was almost as great, apparently, as that by the thirty-foot length.

The whole was then wrapped with cotton batting, and still the anomaly continued. As the mean of two trials the

30 ft. length	gave	19	grams	of	water,	per	foot,	per	hour.
2 ft.	"	" 177	"	"	"	"	"	"	"
Blind 2½ ft.		" 31	"	"	"	"	"	"	"

Now, the blind pipe must have given the most nearly correct result, for whatever entered it had no chance to go beyond or to go back. Hence it is evident that much water was brought in with the steam, and it was not all retained by the first pocket, but some was pushed on into the second; and much that should have run

back into the third pocket, after being condensed in *f*, was thrust forward into the pipe *i*. It seemed quite possible that the cooling in *f* produced mostly floating mist instead of running water, and this mist was swept onward by the current of steam.

As some changes in the boiler connections rendered it necessary to suspend the trials for a time, it was thought best to make a new arrangement of the pipe meanwhile, with a view to obviate the difficulty already experienced. Accordingly the whole structure was altered to the form shown in Fig. 41. The steam was admitted as before through the pipe *a*, and the final outlet was through a trap *t* into a pipe returning to the hot water tank. To the elbow *b* was attached a 2½ ft. blind pipe, to *w* a 10 ft. blind pipe, and to *v* another 5 ft. long. This latter is shown, in side view, in Fig. 42. But all the blind pipes were furnished with the glass siphon tubes like *y*, Fig. 41. The pockets *z* were made of 1¼ inch pipe 2 ft. long. All the siphon pipes *y* were held steady by upright wooden supports not shown in the drawing. The running pipes *e* and *f* were 2 and 30 ft. long respectively.

This arrangement was an improvement on the former one, as it was now possible to compare blind pipes of different lengths; but with the running pipes the anomaly still continued. Thus, after covering only the pockets with cotton batting, an average of 5 trials showed for the condensation per foot per hour:

2½ ft. Blind	178 grams.
5 " "	189 "
10 " "	181 "
2 " Running	328 "
30 " "	140 "

After covering the whole with cotton batting, so that the external diameter was about 4 inches, the apparent condensation in three trials per foot per hour was:

2½ ft. Blind	41	45	46
5 " "	40	40	39
10 " "	38	38	38
2 " Running	143	78	72
30 " "	14	23	28

So while the blind pipes were pretty uniform in their yield, both the running pipes were very variable. The 2 ft. length gave nearly twice as much as it should have done, and the 30 ft. piece gave little more than half of the true quantity. In many other experi-

ments, the results with the running pipes were equally irregular and at variance with the probable truth.

The time required for other experiments did not allow any other transposition of pipes, and therefore I was unable to determine for a certainty why the long running pipe yielded so little condensed water.

It seemed likely that mist or "priming" in the steam might account for some of the irregularities, and so condensation calorimeters were fitted up for testing the quality of the steam. One of these is shown in section in Fig. 43. Fig. 44 shows the same as seen from above, *a* the calorimeter body, made of No. 25 sheet brass, *b* the cover, provided at the top with a short tube *p*, so that the cotton packing may be kept from interfering with the stem *l* of the stirrer *m*. This stem is kept in position by the pin *w* passing through a hole in the brass cross *k*, whose ends are soldered to the bottom of the brass vessel. The stem is steadied by passing through a hole in the wooden crossbar *o*, which is attached to the box *s*. The stem is turned by means of the crank *n*. The stirrer *m* is made of a piece of inch board perforated in the center to receive the stem, and having the opposite long edges shaved down to form screw blades. The brass pipe *e* is for drawing off the water. It is closed at the lower end with the cork *x*. The pipe *c* serves for the introduction of water by means of the removable funnel *r*, and its upper end is closed with a cork when the funnel is taken out. The neck *y* of the calorimeter is extended out at *d*, so that the small pipe *i* may not be disturbed when the cover *b* is taken off, and this side extension is closed with a cork through which the pipe *i* passes. The brass tube *i*, having an internal diameter of one-twelfth of an inch, or 2.1 mm., is soldered at one end to the cap *z*, which screws on the stop-cock *h* connected with the tee *g* of the steam pipe *v*. The tube terminates in the coil *j*, which is open at the end. A thermometer *t* is inserted through the side tube *f* and held fast by a perforated cork.

The brass calorimeter is inclosed in the wooden box *s*, which is large enough to admit a good packing of cotton wool.

A short brass tube is soldered to the inner end of the cock *h*, and extends to the central part of the pipe *v*, so as to receive the best of the steam.

This calorimeter was connected with the tee *x* of Fig. 41. For two others, of simpler construction, the cocks were screwed directly into the elbows *h* and *w*, Fig. 41.

In the first place the water equivalent of the calorimeter must be determined once for all. For this purpose the vessel is filled nearly full of hot water. After stirring well, the temperature is observed. The hot water is run off and cold water of known temperature is quickly let in. The stirrer is turned for a few moments,

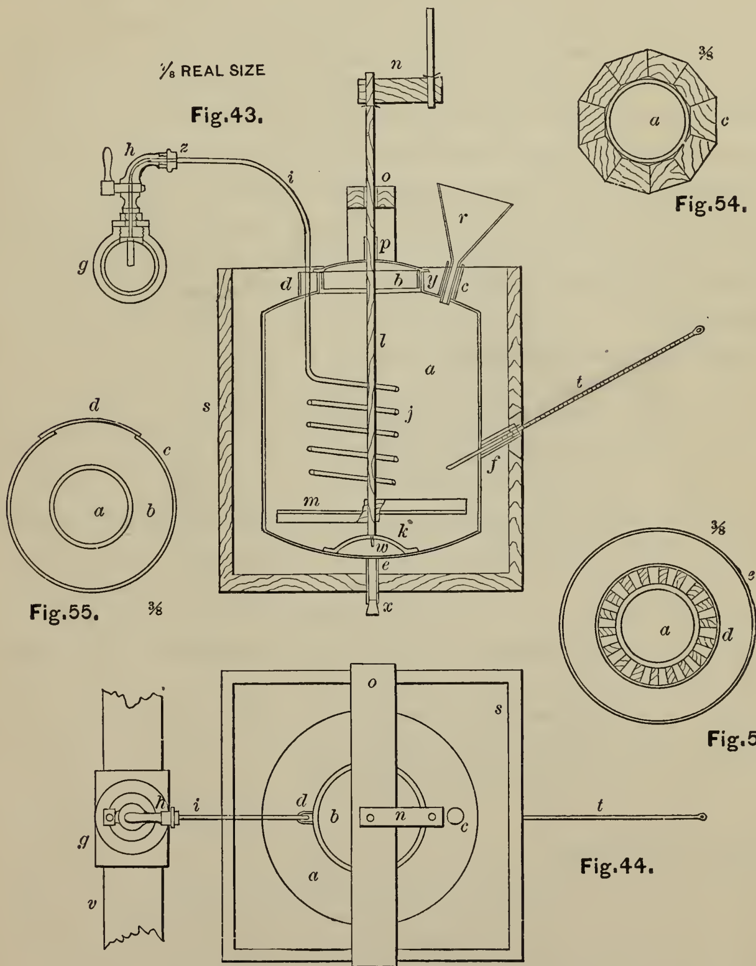

Fig.43.

Fig.54.

Fig.55.

Fig.56.

Fig.44.

and the height of the thermometer is noted. The warmed water is drawn off and weighed.

Now let t' = temperature of hot calorimeter.

t = temperature of cold water.

T = temperature of the warmed water.

a = weight of water finally drawn off.
c = water equivalent of calorimeter itself.

Then
$$c = \frac{a\,(T - t)}{t' - T}.$$

In trying the quality of steam, a weighed quantity of cold water is put into the vessel a (Figs. 43, 44)—about 8 litres, or enough to cover the coil j. After stirring awhile, the height of the thermometer t is noted. Steam from the pipe v is now admitted into the water through the pipe i and the coil j for about three minutes. After a minute or two the temperature is observed, and the warmed water is drawn off and weighed. The temperature of the steam is observed at the beginning and at the end of the experiment by means of the thermometer p, Fig. 41, inserted in a thimble in the steam pipe.

Then let a = weight of cold water.
d = " " hot "
$b = d - a$ = gain in weight.
x = weight of live steam.
$b - x$ = weight of mist.
c = water equivalent of calorimeter, previously found.
t = temperature of cold water.
t' = " " steam.
T = " " hot water.
h = total heat in steam at t', as found in Regnault's tables.
h' = total heat in water at t'.
H = total heat in water at T.
n = latent heat of steam at t'.

It is obvious that
$$\frac{(a + c)\,t + hx + h'\,(b - x)}{a + b + c} = H.$$
or
$$x = \frac{(a + c)\,(H - t) - b\,(h' - H)}{n}.$$

Thus, in one trial, the temperature of the steam was found to be; at

4.17 P.M.	= 155.8°C.
4.22 "	= 155.4°
average	155.6°

$$a = 8080g. \qquad d = 9000g.$$
$$b = 920g. \qquad c = 210g.$$
$$t = 10.4^\circ \qquad h' = 156.9.$$
$$t' = 155.6^\circ \qquad H = 61.85.$$
$$T = 61.7^\circ \qquad n = 496.8.$$

$$x = \frac{(8080 + 210)(61.85 - 10.4) - 920(156.9 - 61.85)}{496.8} = 674.$$

Here, then, were $674g.$ live steam to $246g.$ mist.

In fifty-two such trials, twelve showed a quantity of mist ranging from 7 to 57 per cent. of the whole increase. So what was mentioned in the former report as being a possible source of error in determining the loss of heat from steam pipes by the apparent condensation, proves to be no imaginary trouble. The steam is liable to be, at times, very far from dry, and the damp state may come on and cease undetected in the interval between two trials of quality, unless these trials are kept up in almost unbroken succession. The frequent detection of a faulty condition of things has by no means increased my confidence in the condensation method. Still, when the fireman is skillful and careful and the steam is used the day through for uniform work, the results attained by condensation will often be approximately correct.

It may be of some use, then, to compare the condensation in a covered blind pipe exposed to the air, with the heat radiated into a water calorimeter applied to the covering.

The 30-inch blind pipe, at b, Fig. 41, was covered with straw board so as to inclose a half-inch air space all around, and over this straw board was applied an inch of hair felt, with a wrapper of cotton drilling. When the covering was exposed to the air, the average condensation appeared to be 40 grams per foot per hour.

A calorimeter being applied for 28 inches of the length, the average condensation was 39 grams.

A calorimeter being applied to only 14 inches of the length, while the rest of the covering was exposed to the air, the condensation was apparently 38 grams per foot per hour.

So the transmission into water differed very little in amount from the radiation into the air. And there is little room for the objection to the water calorimeters that they place the coverings under different conditions as to radiation from those which practically occur in ordinary exposure.

The 28-inch calorimeter above mentioned received 20,042 kilo-cent. heat units per foot per hour, which would correspond to a

condensation of 40.3*g.* of dry steam at 156° C. to water at 156°. And considering the uncertainty as to the amount of vaporization during the drawing, and as to the actual temperature of the water before drawing, we may say that the 39 grams actually obtained come quite as near the theoretical yield as could be expected.

Experiments made with a 14-inch calorimeter on the five-foot blind pipe at *v*, Fig. 41, covered with slag wool inclosed in straw board, showed heat given out answering to 33.7*g.* of water condensed, while the actual yield was 31.0*g.*

And trials with a 14-inch calorimeter on the blind pipe at *w*, Fig. 41, covered with silicated cotton-seed hulls, indicated 54.4*g.* steam condensed, there being really only 50 obtained. But the coverings of slag wool and cotton-seed hulls were not perfectly uniform in thickness throughout, and the calorimeters were put on where the thickness was not exactly the average.

As the amount of condensed water increases, and there is consequently a necessity for much more frequent drawing, the loss of water becomes greater. Thus the 30-inch blind pipe was evenly covered with asbestos paper wound round to a total diameter of 4 inches. The water drawn off now amounted to 54*g.* per foot per hour, and at the same time the calorimeter indicated a loss of heat equivalent to the liquefaction of 66*g.* of dry steam.

The 28-inch calorimeter was made partly for trying whether calorimeters of different lengths would show any difference of results, other things being equal. As there was a chance to draw it on over the end of a blind pipe, it was made of a simpler form than those previously described. Fig. 45 gives a side view, Fig. 46 a longitudinal section through *AB* of Fig. 47, which is an end view. Fig. 48 shows a transverse section through *CD*, seen from behind. *a* is the outer shell, *c* the inner. For greater strength the top is swelled out at *b*. The water is poured in through the tube *d* with a loose funnel, *f*; *e* is a tube for drawing off the water, closed with a cork *y*. The thermometer *t* is inserted through the tube *h*, a perforated cork making it tight. Through the neck *l* passes a stirrer which consists of a flat pine paddle, *p*, fastened at the thicker end into the bent brass tube *n*. In the other end of this tube is fastened the wooden handle *m*. The tube turns or oscillates on the pin *r*, which is held by the ears *w*. The shell is made of No. 25 brass. It slips endwise over a covering of moderate diameter and needs no clamps, and as there is no joining of halves the heat is better confined.

In Table III. *h* and *i* show the results of trials of the same covering with the ordinary clamped 14-inch calorimeter, and with this new 28-inch one; the numbers in *i* were found with the new and those in *h* with the older. The difference proves to be too inconsiderable to make it worth the while to use a calorimeter more than

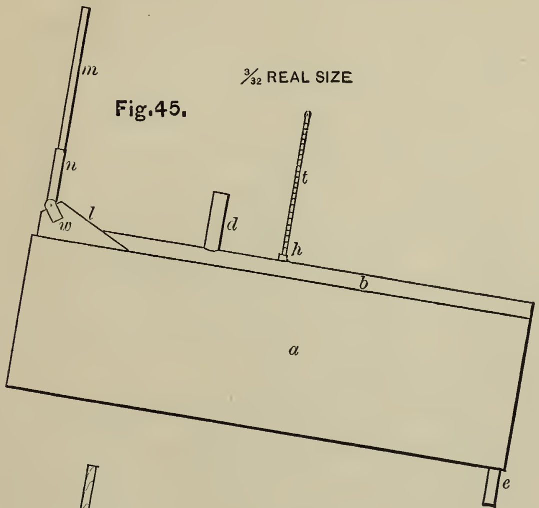

Fig. 45.

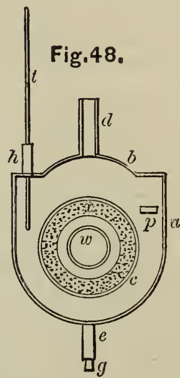

Fig. 48.

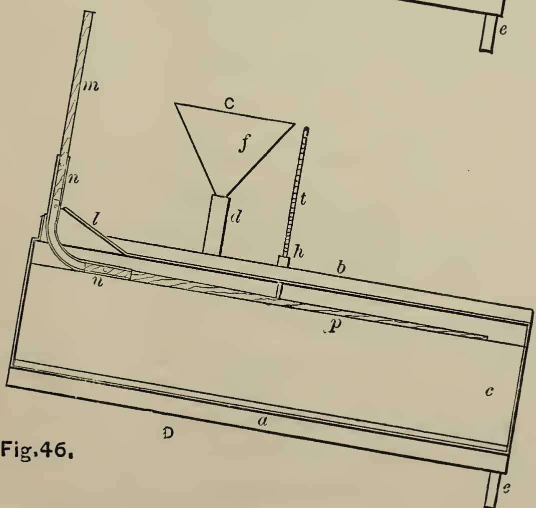

Fig. 46.

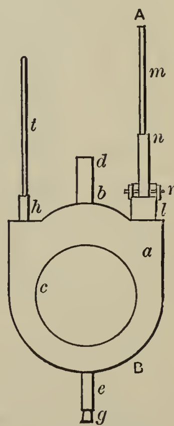

Fig. 47.

14 inches long. A calorimeter of this general form presents some advantages over those made in halves. It has but one inlet, one outlet, one stirrer, one thermometer, and no clamping bolts are required. There is less work in its construction, and somewhat less material. The inner shell can easily be made truly cylindrical,

while it is difficult to get half cylinders exactly right. When one has a blind pipe suitably arranged, the whole calorimeter is more readily applied and more easily supported in place. On the other hand, a blind steam pipe requires a frequent drawing off of the condensed steam, and this gives no little trouble. A second disadvantage is that when a whole cylinder is to be slipped over the covering, from the end, the fit must be rather loose. But this last matter is really of little importance; for experiments have been made to determine whether a loose fit is likely to induce error, and the results are given in Table III., *d*, *e*. The covering, in these cases, was of ground cork and water-glass, moulded on the hot pipe in a wrapper of cotton drilling. The calorimeter used in *d* had an inner diameter of 5⅜ inches, and was so loose that it had to be held in place by wooden wedges. The other, used in *e*, had an inner diameter of 5 inches, and made a very close fit, after some inequalities of the cork had been shaved off. The difference between the 59.2 and 60.1 heat units is no greater than the variations of one and the same calorimeter on successive days.

We may fairly say, therefore, that very close contact of the calorimeter with the pipe covering is by no means essential to accuracy. A little looseness does no harm, if the non-conducting coat of the calorimeter itself is made so close at the ends that no warm air can escape out of the unfilled space.

But when a calorimeter that is somewhat too small is drawn close around an elastic pipe covering, there is a possibility of error, not on account of compression and consequent increase of density, but because the diameter of the covering itself is lessened, and a decrease in the thickness of the non-conductor allows more heat to be transmitted.

This effect of lessened diameter cannot be measured to a nicety with any of the apparatus which I have described hitherto, because it is almost impossible to apply any covering to a cylindrical pipe so as to have it of perfectly uniform and known thickness. So I was led to devise a plan by which coverings might be varied in thickness, and the thickness could be made equable and be exactly measured. The apparatus represented in Figs. 49, 50, 51, 52, 53, dissimilar as it is, was suggested by one contrived by Andrée and described in the *Teksnisk Tidskrift*, xiii., 131. The drawings are made on a scale of one-eighth of the actual size.

Fig. 49 shows a longitudinal vertical section. Fig. 50 gives a longitudinal horizontal section. Fig. 51 represents a vertical cross

section through MN of Fig. 49. Fig. 52 is a side view, and Fig. 53 a front view of the canteen-like calorimeter.

The six-inch steam pipe b was screwed into the caps s and m. The outer flat part of s had been turned to a true surface. At the other end, u was tapped to receive the pipe y, bringing steam, and

1/8 REAL SIZE

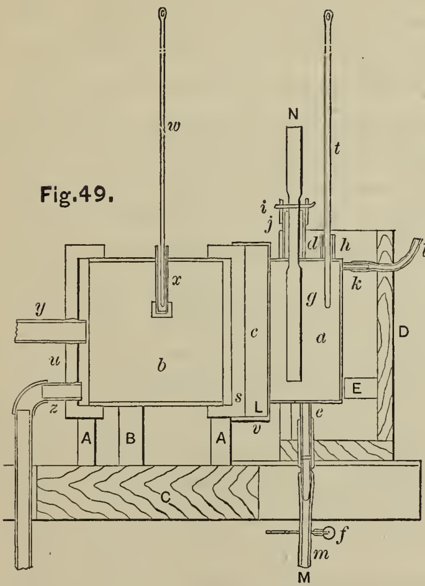

Fig. 49.

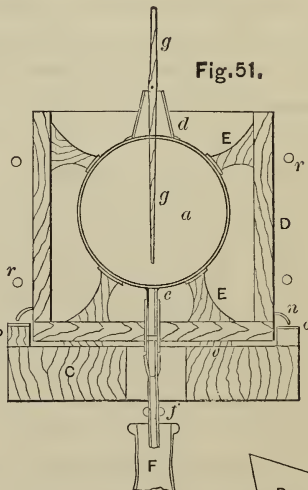

Fig. 51.

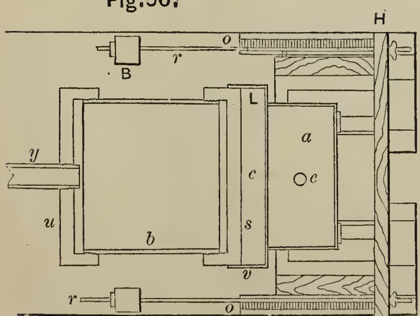

Fig. 50.

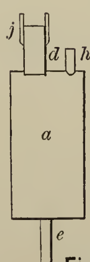

Fig. 52.

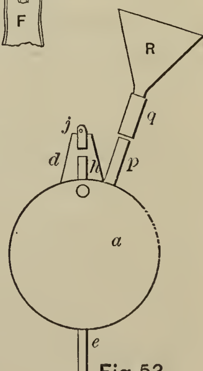

Fig. 53.

the exhaust pipe z. The thimble x, capped at the lower end, was screwed up through the top of the large pipe, to receive the thermomenter w. The calorimeter a, made of thin brass, is provided with the pipe p, through which water may be poured by means of the funnel R. Whenever occasion requires, this funnel is connected

with *p* by an India-rubber tube. Then the funnel is removed, and the end of *q* is corked. The brass outlet pipe *e* is lengthened by an India-rubber tube *m*, which may be opened or closed with the pinch-cock *f*. The tube *h* serves for the insertion of the thermometer *t*, a perforated cork serving to hold the thermometer in place. The $\frac{1}{12}$-inch overflow pipe *k* is lengthened out with an India-rubber tube *l*, which can be turned up after the calorimeter is filled with water. This overflow pipe might be dispensed with, for, in fact, finding out just how much water would fill the brass box, I have generally put in a measured quantity. The neck *d* serves to receive the pine-wood paddle *g*, which turns on the pin *i*, that rests in holes of the ears *j*. These thick brass ears are soldered on, because the neck itself is too thin to support the pin. The calorimeter is held in place in the pine box *D* by the pine supports *E*, bits of thick wool felt being interposed between the props and the brass. The front of the pine box has the projecting ends *H*, through which pass the four bolts *r*. These bolts at the other end pass through holes in the uprights *B*, so that the pine box carrying the calorimeter and sliding on the strips *V* may be adjusted at any distance from the cap *s*, by turning the thumb nuts. The space intervening between the faces of *a* and *s* can be measured exactly on the millimeter scales *o*, with the help of the pointers *n*. The guides *P* keep the faces of *a* and *s* parallel.

The whole is supported at a convenient height on the shelf *C*, the steam box *b* being held up by the soapstone supports *A*. The pine box is well packed within with cotton wool.

A strip of cardboard *v* is drawn around the cap *s*, and fastened to it with water-glass cement, so as to form a hood of any desired depth, for the reception of the different substances whose non-conducting qualities are to be tested. When the substance is a powder, a cardboard ring *L* is secured to the edges of the hood *v* and the calorimeter *a*, by pasting around strips of paper so as to make a tight box, of which the naked calorimeter face forms most of one side, and the face of *s* the other. To allow the powder to be put in, a strip about an inch long is cut out of the top of *v*, and when the whole space has been filled this strip is laid back again, and the whole is made tight by pasting over it a strip of paper somewhat wider and longer. The hood is surrounded with cotton batting during the trial.

When the experiment is completed, a small strip may be cut out of *v*, low down on the cylindrical side, and the powder can be

swept out through the hole. Then the bit of cardboard may be fastened on again by pasting over it a larger piece of paper, and the hood is ready to receive some other substance.

In making a trial, the steam is let into the box *b*, and when the thermometer *w* indicates that the box is fully heated, the calorimeter is filled with water several degrees colder than the air of the room. The time, the height of *w* and *t*, and the temperature of the room at the height of the apparatus are noted down. The observations are often repeated till the water is as much warmer than the average temperature of the air as it was colder at first. Of course the paddle *g* must be well oscillated before every observation. Finally, the water is drawn into a flask and weighed.

The necessary calculations are not very complicated. Thus in one experiment with fossil meal:

Water at first was at............................	5.8° C.
" " last "	31.5°
Gain therefore = ...	25.7°
Average temperature of room..................	18.4°
" " " steam..................	154.1°
Time =..	299 minutes.
Weight of water = ...	1,326 grams.
Water equivalent of calorimeter =.............	50 "
Surface of calorimeter face =.......0.0182 sq. m. =	0.196 sq. ft.

$\frac{60}{299} \times \frac{1326 + 50}{1000} \times \frac{25.7}{0.0182} = 389.9$ kilo-cent. heat units per sq. meter per hour; or,

$\frac{60}{299} \times \frac{1376}{1000} \times \frac{25.7}{0.196} \times \frac{9}{5} \times 2.205 = 143.7$ Pound-Fahrenheit heat units per sq. foot per hour.

Generally, at least three trials have been made and the results have been averaged. But in the case of animal and vegetable fibers it is hardly worth the while to repeat experiments with the same lot, because these organic matters are considerably scorched by a few hours' exposure to a heat of 155° C., and of course they are no longer the same substances as before. For such things it would be better to have, instead of steam, a current of hot water, of constant temperature, running through the box.

The pointers being arranged, in the first place, to indicate 0 when the faces of the calorimeter and the steam-box are in contact, of course the thickness of the stratum to be tried can be measured

very exactly. Moreover, an elastic, coherent substance, like wool, can be compressed to any desired degree by turning the four thumb-nuts. But when a powder is to be compressed a little, it may be crowded into the tight hood at the top aperture by ramming. Such powders as can be made to cohere by strong pressure, like magnesia and zinc white, may be compacted by forcing them into a mould with a powerful press. The cake being made a little large, can be shaved to the required dimensions, the edges being trimmed so that the disc will just slip into the open hood.

This apparatus is very convenient, and requires but a moderate amount of material for a trial. It would be still better to have both caps turned to true faces, so that two calorimeters could be used at a time, for it is almost as easy to attend to two trials as to one. In this case, of course, the steam pipes would be let into the cylindrical sides of the steam box.

Tables V. and VI. give the results of a series of experiments extending through four months.

The first column gives the names of the substances tried. The second shows their thickness in millimeters. The numbers in the third column are obtained by calculating the weight of 1,000 cubic centimeters of the substance from the known bulk and the weight as determined when the trial was just finished, while the stuff was in its driest state. The specific gravities given in the fourth column were determined by weighing under a liquid which expelled all the air. The animal and vegetable fibers, lampblack, magnesia, cork, charcoal, plaster of Paris, plumbago and chloride of sodium were weighed in toluol, the rest were tried with water. There may be some doubt about the feathers in 13 and 24, as it is exceedingly hard to get all the air out of them. The weight per litre, divided by the specific gravity and by ten, shows what percentage of the whole bulk is occupied by solid matter, the rest being the air in the interstitial spaces. Thus in No. 2 there is only one cubic centimeter of cellulose to 99 c. c. of air, and the great efficiency of this soft pad is almost wholly due to the stagnant air. The sixth column shows how many kilograms of water would be raised 1° C. by the heat which the substance in question transmits in an hour, through each square metre of the specified thickness, the surfaces being flat. In the last column these numbers have been multiplied by $2.205 \times 1.8 \times 0.0929 = 0.3687$, to find how many pounds of water would be heated 1° F. in an hour for every square foot of the transmitting surface.

In Table V. the substances are arranged and numbered in the order of efficiency. In Table VI. the numberings correspond to those of Table V., but the arrangement is by groups of the same substance in different states and thicknesses. After organic fibers come the different varieties of carbon; then Pattinson's calcined magnesia, and magnesia alba; then the different forms of silica. From "Omahalite" on, there is little chance for grouping. What I have called Omahalite, for convenience, in Nos. 42, 43, is a very light mineral, in coarse powder, which was sent from Omaha, Neb., for trial. It had been separated into the coarse and the fine by sifting. The fine contained about 70 per cent. of silica, 7 of alkalis, 15 of alumina, and 8 of water. It is in small scales, appearing under the microscope like fragments of skeleton crystals, and owes its lightness to its scaly character. Whatever other economic value it may have, it certainly has very little for covering steam pipes.

In Table VI., 1, 3, 4, 26, 36, 39, the same lot of wadding was tried first 50 mm. thick, then it was screwed up to 40, then to 30, and so on. In 2 and 17 the same lot of carded cotton was used, and in 23 the outer half of it was tried. But in 10, 20, and 21 a new quantity of the very clean soft batting was used. In 13 and 24, the feathers were put into a bag of very thin muslin, new feathers being taken each time.

The sand which was to be used in 52, 53, was first well washed, so as to float off the finest part, and the residue, after drying, was sifted with a sieve of 20 meshes to the linear inch. What passed through was separated into coarse and fine with a sieve of 40 meshes to the inch. It was nearly pure quartz. The Plymouth sand was treated with muriatic acid, and well washed to take out the oxide of iron. After drying, it was passed through a silk bolting cloth of 14,400 meshes to the square inch.

The fossil meal, before being used for 34 and 37, was separated by elutriation from about 20 per cent. of sand.

Table VII., including only such trials as were made with the uniform thickness of 25 millimeters of material, is arranged according to the bulk of air contained in 100 measures of the substances as they were used. This table may serve to facilitate the comparison of different articles occupying nearly the same absolute space, such as the groups *d*, *e*, *f*, *g*—*i*, *j*—*r*, *s*—*G*, *H*—*R*, *S*.

The table shows what astonishing air traps are many of the non-conductors that we have to deal with. We need not wonder that the calcined magnesia of the druggist acts so much like a fluid, for

every particle surrounds itself with a thick air cushion, and about 98 per cent. of the space that it fills is taken up by the elastic fluid.

It was very desirable to find the conducting power of discs of solid chalk, heavy spar, quartz, plumbago, rock salt, and anthracite coal, since these additional data are needed for a full discussion of the results already obtained. But time was lacking.

With other than compact solid substances, the results are of course complex, as they depend partly on the closeness of contact of the particles of solid matter, partly on their specific conducting power and partly on the friction which the particles exert on the included air. The fewer the points of contact of the solid grains, the less chance will there be for the transmission of heat by conduction; and the more rigidly the air is held in the interstices, the less transmission will there be by convection. Air alone, as is shown by 50 in the tables, transfers much heat when it can move about in a closed space—unless, indeed, the source of heat is placed at the top. The usefulness of mere air spaces has been much overestimated, for they can rarely be placed so as to render much service.

The air no doubt slides much more freely over smooth particles, like those of plumbago, and this must account, in part, for the great difference between the efficiency of the same absolute bulk of chalk and black lead, as shown in *I J*, Table VII. And it is not unlikely that the great difference between wool and asbestos, as shown in *u* and *v*, is largely due to the smoothness of the soapy mineral fiber. It is hard to conceive of anything better fitted to counteract the mobility of air than the irregular twists of flattened cotton fiber, the crinkles and scaliness of wool, the fringed edges of down filaments, or the feathered angles of snow crystals. The wonderful structure of the minute diatoms which make up fossil meal also accounts for the efficiency of this light silica as a non-conductor.

When more and more organic fiber is crowded into a given space, the thickness of the stratum remaining the same, the transmissive power appears to be diminished till a certain limit is reached, beyond which there comes an increase. Probably then the mobility of the air has been brought to a minimum, and the proper conducting power of the fiber begins to act more decidedly.

The statement of Peclèt requires some qualification when he says: * "Il est important de remarquer, que la conductibilité des matières textiles étant sensiblement indépendante de leur densité;

* Traité de la Chaleur. 3me Ed., i. 407.

il s'ensuit necessairement que leur conductibilité est la même que celle de l'air stagnant."

The tables show that the compression of non-fibrous matters, like lampblack, fossil meal, magnesia, and zinc white, increases the conducting power in a marked degree. And this is a strong argument against using such things in the form of a paste to be plastered on.

But it is worth the while also to notice, as a matter of much practical and economic importance, that the quantity of the substance remaining the same, compression which lessens the thickness of a covering thereby decreases its heat-retaining power in no small degree. This may be seen from the trials 1, 3, 4, 26, 36, and 39, in Table VI., in which the same quantity of wadding was successively reduced to 40, 30, 20, 15, and 10 mm. in thickness, and the transmission was at last almost quadrupled. Also, in 2 and 17, the same carded cotton was condensed from 50 to 25 mm. thick, and the efficiency was lessened 44 per cent.

The obvious moral is: Use any non-conductor light and thick, rather than dense and thin.

Many new experiments on actual pipe coverings have been made, to supplement those of which an account is given in the former report, and the results are shown in Table III., in the order of efficiency. Table IV. includes the items of Table III., and those of all but the more complex coverings of Table I., arranged in groups so as to show the effect of various substances used in different ways. Thus, those specimens in which hair-felt forms the prominent constituent are put first, and those are brought together in which an air space is a characteristic feature.

For slag wool, ashes, dry fossil meal, and mere rice hulls, cases of straw board were made around the pipe, as formerly described, except that the straw board was shaped by binding it, while damp, around a cylinder of the right size and letting it dry before taking off. Fig. 30 shows a transverse section of such a case, *a* being the pipe, *b* the hollow space, and *c* the case with its cover *d*.

Air spaces were made with smaller straw board cases, held off from the pipe by flexible rings. These rings may be made of narrow strips of cardboard, which are painted over on the inner side with water-glass; then cheap vial corks are stuck on endwise, and the whole is bent around the pipe as shown in Fig. 56, *d*, and held in place by pasting down the overlapping end of the cardboard. Or bits of thick asbestos cord may be wet with water-glass and drawn around the hot pipe. Or, again, long strips of thick paper coated with the adhesive

silicate may be wound round and round till they have formed the desired thickness. But the air spaces in 47 and 48 were formed by the calorimeters themselves, paper props being used at the ends. In 19, the space was $\frac{1}{4}$ inch thick, in the rest about $\frac{1}{2}$ inch. The multiplex air spaces of *u* were made by winding around the pipe spirally some asbestos wicking, then putting on silicated straw-board, then winding around a spiral of hemp cord, and so on till there were four spiral cords and four cases.

The result of the multiplex arrangement was not good enough to pay for the trouble and cost; but, by comparing *u* with 48, we see that a much divided air space is better than a simple one.

Comparison of *h* and 20 with 1 and 2, of 19 with 16, and of *o* with *l*, do not turn out to the advantage of air spaces. And in 34 and 36 we see that the slight gain will not pay for the extra cost of material. It would be better in all cases to fill up the air space with fossil meal, which would be far more efficient in preventing the scorching of the organic matter.

A mixture of fossil meal with one-seventh of its weight of cork sawdust proved somewhat more efficacious than fossil meal alone; but as both were used as they were procured in the market, possibly the fossil meal was not just alike in the two cases. Indeed, the article used in *c*, on examination proved to be not the best, for by washing it yielded 20 per cent. of sand. Another sample was obtained, but not used, for it contained much more sand, and, as it had been burned, there were many hard baked lumps in it. For the use in question, diatomaceous earth ought to be freed from sand and left unburned. From its peculiar structure it is more tractable than other light powders like ashes or magnesia, and it can easily be applied in the dry state, in which it seems to have the maximum efficiency. As this substance is abundant in various parts of the world, and can be afforded at a low price, it is likely to come into pretty general use for coverings. It works quite as well as slag wool, and is not liable to the same objections. Its dust is not irritating; it is not decomposed by heat, moisture, and carbonic acid; it does not undergo continual shrinkage by jarring; it does not cause the corrosion of pipes.

I was able at length to get some slag wool of the best quality, very light, tolerably elastic, and almost wholly free from shot-like particles of slag. This was applied to the whole length of the blind 5-foot pipe (*v*, Fig. 41). It gave a very good result, as shown in *b*, Table IV.

After making the trial, a portion of the cover of the straw-board case was removed, and water was poured in from time to time and allowed to evaporate. This was done for about four weeks. The inner part thus became a more compacted mass, crushing easily between the fingers to a somewhat spicular powder. Water digested with this became very faintly alkaline, and showed the presence of a sulphate. Of course, a part of the sulphide of calcium in the original substance had been oxidized to sulphate. The steam pipe was not particularly rusty. In a published account of some cases of corrosion said to be caused by slag wool,* it is suggested that sulphuric acid had been set free and had acted on the iron, but the author does not explain how the acid could be set free from a strong base when there is an excess of the base present. Chemists will hardly admit that sulphate of calcium can be dissociated by anything short of an intense red heat. Sulphate of calcium promotes the oxidation of iron, as every one knows who has left wet plaster of Paris in contact with the metal; but it is not because sulphuric acid is set free first.

The slag wool of $35\frac{1}{2}$ was not of as good quality as that used in *b*, and it was not thick enough to do well.

One of the best non-conductors is cork. It is strong, elastic, waterproof, and not very changeable. The "Société Anonyme des Lièges Appliquées à l'Industrie," of Paris, manufactures envelopes for steam pipes, boilers, etc., of long strips of cork, so beveled at the edges as to fit exactly and form a polygonal prism, which is bound together with tinned wire. Such a covering, on account of its firmness and elasticity, is particularly suitable for locomotives, or any other apparatus exposed to jarring and shocks; but it is necessarily expensive, when the strips are made thick enough. By the kindness of the director of the company, I have received a covering long enough for a trial. It is made in 10 pieces, as shown in cross section in Fig. 44. Being hardly $\frac{5}{8}$ in. thick, this covering does not give a very favorable result. A greater thickness of this excellent material may be secured at very moderate cost, by cementing finely cut waste fragments of cork with water-glass. This conglomerate has not the strength of solid cork, but it makes a pretty firm and elastic coat, and when protected with a cloth wrapper it forms one of the best coverings yet tried. For the experiments *d*, *e*, parings of bottle-corks were cut up with a sausage-meat cutter, and moistened with one and a half times their weight of

* Transactions A. S. M. E., Vol. III., p. 230.

water-glass at 30° Baumé, and this mixture was applied to the hot pipe with the help of a wire cage. The water-glass does not soak in, but coats every bit of cork superficially, and so its cementing power is exerted to the best advantage. Thus by drying, the mass becomes strongly coherent. This covering can also be moulded in halves, without the cloth, and after drying it will bear handling. Prepared in this way, it can be applied to the pipe with great ease, and may be held on by putting around paper or cloth. As the inner surface becomes somewhat changed by long heating, it would be better to make larger half-shells of cork, and line them with $\frac{3}{8}$ or $\frac{1}{2}$ in. of fossil-meal paste. A covering made in this latter way I have not yet had a chance to try, but I believe it is, in all respects, one of the very best that could be devised.

For other coverings with a water-glass cement, I have tried rice chaff, cotton-seed hulls, and pine charcoal. The rice chaff requires its own weight of water-glass, and this ought to have the strength of 35° B. I used it at 30° B., and though for a while after drying the chaff was coherent, in the course of a few weeks the adhesion was very much impaired.

The cotton-seed hulls were those of rough seed cotton, covered with a short furze, which makes them lie light and loose. The hulls were mixed with twice their weight of water-glass at 30° B. It took some time for this mass to become dry, but it was pretty firm and elastic, and remained so. It is difficult to get an even coating with the rough woolly mixture, and this material proved less effective than some other things.

The charcoal was made of white pine wood by distilling in a pyroligneous acid retort holding a cord. It was ground up in a corn-cracking mill, and moistened with $1\frac{1}{2}$ times its weight of water-glass at 30° B. When dry the mass was coherent, and continued so, though a water-glass a little stronger would have been better.

I am thus particular to give the proper weight of the water-glass liquid, because a novice would be apt to put in a great deal more than is needed; and when the mixture is used too wet, the excess of liquid drains to the under side, and makes an unpleasant dripping. It is much better to take just enough, and stir patiently till a slight, uniform moistening is effected. Then the damp mixture may be inclosed in cloth, with the aid of the wire cage, and the water-glass does not come through the cloth. The mixture may be done easily with a hoe in a mortar-box.

Pine charcoal proves better than hard wood coal, and probably charred cork or tan-bark would be still better.

The stair or carpet pad of *p* and *v* is made of rolls of cotton roving laid side by side, knit together with cotton yarn by machinery. It is too expensive and combustible to be used for steam pipes, even if it made a more advantageous showing than it does.

The paper used in *w* did much worse than was expected. This covering was made by cementing the edge of a sheet of the best blotting paper along the pipe with water-glass and winding the paper around as tightly as possible. The other edge was pasted down with water-glass. Over this another sheet was applied in the same way, and so on, till the thickness of three-quarters of an inch was reached.

The asbestos paper of *x* was put on in the same way. Strangely enough the mineral and the vegetable paper show nearly the same conducting power. Paper that is to be used for non-conductors should evidently be made soft and spongy, like that of 16.

The ashes of *q* were taken from the 3-in. tubes of a boiler, and those of *r* and *y* were sent in for trial.

The carbon which made the plastered mass of 34 superior to that of 44 was what is left when the black liquor from the soda boil of wood paper pulp is dried down and the ignited residue is leached with water to recover the soda. It is something between ordinary charcoal and lamp-black.

As the outcome of what has been done hitherto we may say:

1. Trials of steam-pipe coverings by the method of condensation are liable to errors on account of the not infrequent priming of steam which may occur at any time of day. It is also difficult to draw off, without loss, the water that is condensed.

2. Some method depending on a constant temperature in the pipe, which can be looked to at any and all times, is preferable to one dependent on the dryness of steam, which is a matter that cannot be constantly watched.

3. The transmission of heat into the water of a calorimeter does not differ materially from that into free air.

4. The calorimetric method is preferable as being applicable to running pipes, and not requiring any special arrangement of side branches.

5. It is useless to make the testing apparatus of cumbrous dimensions, for as in chemical analysis we use a gram or less of the sam-

ple, instead of kilograms, so in physical experiments increase of size does not necessarily enhance the accuracy of the results.

6. Air chambers in pipe coverings are not advantageous, but it is better to fill hollow places with some light powder.

7. Compression lessens the actual efficiency of loose powders or fibres, by diminishing the thickness of the covering.

8. Of all the substances tried, the most advantageous are hair felt, cork, fossil meal, magnesia, charcoal, and rice chaff.

Slag wool would also be good if it could be made of a silicious slag free from sulphide of calcium.

Lamp-black is very efficient, and might do if it were not combustible and unpleasant to handle.

At first it might seem as though magnesia is too costly to be taken into account, but with the great abundance of useless magnesium salts in the Stassfurt deposits and the present exceedingly low price of soda ash, there is nothing but lack of demand to hinder a very economical production of magnesia alba, or even of calcined magnesia, the lightest and nicest of all incombustible non-conductors.

The following tables give the results obtained in this investigation since the preparation of the former paper on this subject, and which contains tables I. and II.*

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* See Transactions A. S. M. E., Vol. V., p. 95, *et seq.*

TABLE III.

		Diameter in Millim.	Weight per meter in grams.	Kilo-Cent. heat units 1 m. 1 h.	Diameter in inches.	Weight per foot in oz. av.	Pound Fahr. heat unit 1 foot, 1 hour.
a	Fossil meal and cork (12 p. c.), straw board	130	2,297	53.6	$5\frac{1}{8}$	24.7	64.8
b	Best slag wool, straw board	121	1,228	55.1	$4\frac{3}{4}$	13.2	66.6
c	Dry fossil meal, straw board	130	1,934	56.6	$5\frac{1}{8}$	20.8	68.4
d	Silicated cork chips, drilling (calorimeter loose)	133	1,366	59.2	$5\frac{1}{4}$	14.8	71.4
e	Silicated cork chips, drilling (calorimeter close)	133	1,376	60 1	$5\frac{1}{4}$	14.7	72.7
f	Silicated pine charcoal, drilling	133	3,208	64.7	$5\frac{1}{4}$	34.5	78.3
g	Air space, straw board, cork chips, straw board	130	1,116	65.3	$5\frac{1}{8}$	12.0	79.0
h	Air space, straw board, hair felt, drilling (short cal.)	130		65.3	$5\frac{1}{8}$		79.0
i	Air space, straw board, hair felt, drilling (long cal.)	130		65.8	$5\frac{1}{8}$		79.5
j	Cotton batting, cotton cloth	102	558	65.9	4	6.0	79.7
k	Silicated rice chaff, drilling	133	1,627	70.6	$5\frac{1}{4}$	17.5	85.4
l	Dry rice chaff, straw board	130	1,553	71.9	$5\frac{1}{8}$	16.7	87.0
m	Air space, straw board, pine turnings, straw board	130	1,302	74.1	$5\frac{1}{8}$	14.0	89.6
n	Air space, straw board, paper pulp, straw board	130	1,274	75.8	$5\frac{1}{8}$	13.7	91.7
o	Air space, straw board, rice chaff, straw board	130	1,590	78.1	$5\frac{1}{8}$	17.1	94.5
p	Air space, straw board, cotton roving	121	1,357	79.3	$4\frac{3}{4}$	14.6	96.0
q	Anthracite fine dust, straw board	127	3,497	80.1	5	37.6	96.8
r	Bituminous coal ashes, straw board	127	3,832	81.3	5	41.2	98.4
s	Cork chips	92	623	87.1	$3\frac{5}{8}$	6.7	105.3
t	Silicated cotton seed hulls	130	4,743	88.9	$5\frac{1}{8}$	51.0	107.6
u	Multiplex air spaces with straw board and cords	111	2,613	95.4	$4\frac{3}{8}$	28.1	115.3
v	Air space, straw board, thin cotton roving	108	772	102.6	$4\frac{1}{4}$	8.3	124.0
w	Blotting paper	102	2,688	105.6	4	28.9	127.8
x	Asbestos paper	102		108.5	4		131.2
y	Anthracite coal ashes	130	5,329	108.5	$5\frac{1}{8}$	57.3	131.2

TABLE IV.

		Diameter of covering in Millim.	Weight per linear meter in grams.	Kilo-Cent. heat units 1 meter 1h.	Diameter in inches.	Weight per foot in oz. Av.	Pound Fahr. heat units 1 foot, 1 hour.
1	Hair felt, burlap	137	1,990	42.1	5.37	21.4	51.0
2	" " "	114	1,228	42.6	4.5	13.2	51.6
5	Asbestos paper, hair felt, duck	114	1,609	49.5	4.5	17.3	59.7
7	" " " " paper, duck	114	1,851	51.7	4.5	19.9	62.5
8	" " " " " "	127	1,711	52.7	5	18.4	63.8
11	" " " " " "	102	1,600	58.4	4	17.2	70.6
15	" " " " " "	114	1,498	64.4	4.5	16.1	77.9
a	Fossil meal and cork (12 p. c.); straw board	130	2,297	53.6	5.12	24.7	64.8
c	Fossil meal, straw board	130	1,934	56.6	5.12	20.8	68.4
21	Paste of fossil meal and hair	121	5,647	69.4	4.75	60.7	83.9
26	" " " " "	108	2,967	75.3	4.25	31.9	91.0
27	" " " " "	105	2,502	77.0	4.12	26.9	93.1
36	" " " " asbestos	114	3,199	97.1	4.5	34.4	117.5
b	Best slag wool, straw board	121	1,228	55.1	4.75	13.2	66.6
24	Poor " " " "	108	2,241	74.8	4.25	24.1	90.5
35½	Asbestos paper, slag wool, asbestos paper	102	2,437	96.8	4	26.2	117.0
9	Air space, tin plate, hair felt, duck	120	1,934	56.2	4.75	20.8	67.9
g	" " straw board, cork, straw board	130	1,116	65.3	5.12	12.0	79.0
h	" " " " hair felt, drilling	130		65.3	5.12		79.0
i	" " " " " " "	130		65.8	5.12		79.5
19	" " asbestos paper, paper cylinder	121	2,725	67.1	4.75	29.3	81.1
20	" " straw board, hair felt	121	1,116	67.9	4.75	12.0	82.1
22	" " " " sphagnum, cotton cloth	121	986	71.0	4.75	10.6	85.8
m	" " " " pine turnings, straw board	130	1,302	74.1	5.12	14.0	89.6
n	" " " " paper pulp, " "	130	1,274	75.8	5.12	13.7	91.7
o	" " " " rice chaff, " "	130	1,590	78.1	5.12	17.1	94.6
p	" " " " cotton roving stair pad	121	1,357	79.3	4.75	14.6	96.0
34	" " wire netting, paste of fossil meal and asbestos	127	3,813	93.8	5	41.0	113.4
u	" " multiplex	111	2,613	95.4	4.37	28.1	115.3

v	Air space, straw board, cotton roving	108	772	102.6	4.25	8.3	124.0
47	" " simple	75		161.6	2.94		195.4
48	" " simple	121		165.4	4.75		200.0
d	Silicated cork chips, drilling (loose calorimeter)	133	1,376	59.2	5.25	14.8	71.4
e	" " " " (close calorimeter)	133	1,367	60.1	5.25	14.7	72.7
g	Air space, straw board, cork chips, straw board	130	1,116	65.3	5.12	12.0	79.0
s	Cork in strips	92	623	87.1	3.62	6.7	105.3
f	Silicated pine charcoal	133	3,208	64.7	5.25	34.5	78.3
29	" hard wood charcoal	127	3,896	80.9	5	41.9	97.8
18	" rice chaff, cotton cloth	121	2,111	66.3	4.75	22.7	80.2
k	" " " drilling	133	1,627	70.6	5.25	17.5	85 4
l	Rice chaff, straw board	130	1,554	71.9	5.12	16.7	87.0
o	Air space, straw board, rice chaff, straw board	130	1,590	78.1	5.12	17.1	94.5
32	Rice chaff, straw board	95	781	90.6	3.75	8.4	109.5
16	Paper cylinder—Reed's covering	111	2,837	64.5	4.37	30 5	78.1
j	Cotton batting	102	558	65.9	4	6.0	79.7
19	Air space, asbestos paper, paper cylinder—Reed's covering	121	2,725	67.1	4.75	29.3	81.1
28	Straw rope, quadruple cotton cloth	114	1,879	80.1	4.50	20.2	96.9
t	Silicated cotton-seed hulls, drilling	130	4,743	88.9	5 12	51.0	107.6
w	Blotting paper	102	2,688	105.6	4	28.9	127.8
x	Asbestos paper	102		108.5	4		131.2
50	" "	73		184.9	2.87		223.7
q	Anthracite coal flue ashes, straw board	127	3,497	80.1	5	37.6	96.8
v	Bituminous coal ashes, " "	127	3,832	81.3	5	41 2	98.4
y	Anthracite coal ashes, " "	130	5,329	108.5	5.12	57.3	131.2
21	Paste of fossil meal and hair, plastered on	121	5,647	69.4	4.75	60.7	83.9
26	" " " " " " " "	108	2,967	75.3	4.25	31.9	91.0
27	" " " " " " " "	105	2,502	77.0	4.12	26.9	93.1
34	Air space, paste of fossil meal and asbestos	127	3,813	93.8	5	41.0	113.4
36	Paste of fossil meal and asbestos	114	3,199	97.1	4.50	34.4	117.5
30	Carbon, plaster of Paris, flour and hair, in paste, plastered on	114	3,069	88.3	4.50	33 0	106.8
42	Paste of clay and vegetable fibre, plastered on	133	8,751	120.7	5.25	94.1	146.0
44	Paste of anthracite ashes, plaster of Paris, flour, and hair	121	7,366	128 5	4.75	79.2	155.4
49	Paste of clay and vegetable fibre	108	7,633	169.7	4.25	65.2	205.3

TABLE V.

		Thickness in Millim.	Weight in 1,000 c. c.	Net Specific Gravity.	Per cent. solid matter.	Kilo-Cent. heat units 1 sq. m. 1 h.	Lb. Fahr. heat units 1 sq. ft. 1 h.
1	Glazed cotton wadding	50	15.8*g*.	1.55	1.0	129.1	47.6
2	Carded cotton	50	15.8	1.58	1.0	157.7	58.1
3	Glazed cotton wadding	40	19.7	1.55	1.3	193.4	71.3
4	Glazed cotton wadding	30	26.4	"	1.7	205.5	75.8
5	Wool wadding	25	73.1	1.31	5.6	219.8	81.0
6	Wool wadding	25	90.4	"	6.9	223.6	82.4
7	Wool wadding	25	126.8	"	9.7	237.4	87.5
8	Wool wadding	25	103.9	"	7.9	238.5	87.9
9	Wool wadding	25	118.0	"	9.0	246.2	90.8
10	French cotton wadding	25	65.7	1.58	4.1	247.7	91.3
11	Wool wadding	25	56.8	1.31	4.3	253.1	93.3
12	Cotton roving knit together	28	128.5	1.58	8.1	257.1	95.0
13	Live geese feathers	25	50.5	1.01	5.0	261.6	96.4
14	Lampblack, loose	25	95.0	1.70	5.6	266.5	98.3
15	Hair felt	25	242.7	1.31	18.5	277.4	102.3
16	Wool wadding	25	40.9	1.31	3.1	279.1	102.9
17	Carded cotton	25	31.5	1.58	2.0	281.4	103.7
18	Lampblack. compressed	25	415.0	1.70	24.4	286.5	105.6
19	Hair felt	25	121.3	1.31	9.2	292 8	107.9
20	French cotton batting	25	13.8	1.58	0.9	298.7	110.1
21	French cotton batting	25	30.5	1.58	1.9	299.5	110.4
22	Wool wadding	25	27.3	1.31	2.1	300.6	110.8
23	Carded cotton	25	16.1	1.58	1.0	310.4	114.4
24	Live geese feathers	25	20.0	1.01	2.0	320.9	118.4
25	Cork charcoal, ground fine	25	78.7	1.43	5.3	323.6	119.3
26	Glazed cotton wadding	20	39.5	1.55	2.5	326.4	120.3
27	Calcined magnesia, loose	25	76.0	3.26	2.3	335.2	123.6
28	Calcined magnesia, crowded	25	160.0	3.26	4.9	340.1	125.4
29	Cork charcoal, coarsely ground	25	45.0	1.43	3.1	343.4	126.5

30	Glazed cotton wadding	20	18.3	1.55	1.2	370.9	136.6
31	Carbonate of magnesia = "magnesia alba."	25	132.	2.21	6.0	370.9	136.6
32	Pine charcoal	"	163.	1.37	11.9	376.4	138.8
33	Carbonate of magnesia, crowded	"	207.	2.21	9.4	386.7	142.6
34	Washed fossil meal, loose	"	147.	2.44	6.0	393.4	145.1
35	Carbonate of magnesia, compressed	"	333.	2.21	15.0	416.5	153.6
36	Glazed cotton wadding	15	52.7	1.55	3.4	424.2	156.4
37	Washed fossil meal, crowded	25	273.	2.44	11.2	425.8	157.0
38	French zinc white, loose	25	483.	5.48	8.8	466.0	171.8
39	Glazed cotton wadding	10	79.1	1.55	5.1	502.4	185.2
40	Paris white = carbonate calcium	25	781.	3.09	25.3	559.6	206.3
41	Barium sulphate, fine flour	"	179.2	4.70	38.1	728.6	268.6
42	Coarse Omahalite	"	491.	2.62	18.7	777.5	286.6
43	Fine Omahalite	"	628.	2.54	24.7	823.1	303.5
44	Plaster Paris = anhydrous calcium sulphate	"	964.	2.62	36.8	839.2	309.4
45	Pumice stone, finely ground	"	873.	2.55	34.2	844 6	311.4
46	Extremely fine sand from Plymouth, Mass.	"	991.	2.78	35.6	861.0	317.5
47	Anthracite coal, ground	"	827.	1.63	50.6	968.2	357.0
48	Calcined magnesia, compressed	"	931.	3.26	28.5	1,155.9	426.0
49	Zinc white, compressed	"	177.2	5.48	32.3	1,163.8	429.1
50	Air space	"	1.2	0.0	0.0	1,391.7	479.9
51	Fibrous asbestos	"	247.	3.05	8.1	1,328.6	489.9
52	Coarse sand	"	143.9	2.72	52.9	1,683.6	620.7
53	Fine sand	"	140.8	2.74	51.4	1,689.7	629.0
54	Plumbago	"	628.	2.40	26.1	1,922.5	708.8
55	Fine table salt = sodium chloride	"	103.2	2.15	48.0	1,982.7	731.0

TABLE VI.

		Thickness in Millimeters.	Weight in 1,000 c. c.	Net specific gravity.	Per cent. solid matter.	Kilo-Cent. heat units 1 sq. in. 1 h.	Pound-Fah. heat units 1 sq. ft. 1 h.
1	Glazed cotton wadding	50	15.8	1.55	1.0	129.1	47.6
3	" " "	40	19.7	1.55	1.3	193.4	71.3
4	" " "	30	26.4	1.55	1.7	205.5	75.8
26	" " "	20	39.5	1.55	2.5	326.4	120.3
30	" " "	20	18.3	1.55	1.2	370.9	136.6
36	" " "	15	52.7	1.55	3.4	424.2	156.4
39	" " "	10	79.1	1.55	5.1	502.4	185.2
2	Carded cotton	50	15.8	1.58	1.0	157.7	58.1
17	" "	25	31.5	1.58	2.0	281.4	103.7
23	" "	25	16.1	1.58	1.0	310.4	114.4
10	French cotton batting	25	65.7	1.58	4.1	247.7	91.3
20	" " "	25	13.8	1.58	0.9	298.7	110.1
21	" " "	25	30.5	1.58	1.9	299.5	110.4
12	Cotton roving, stair pad	28	128.5	1.58	8.1	257.1	95.0
5	Wool wadding	25	73.1	1.31	5.6	219.8	81.0
6	" "	25	90.4	1.31	6.9	223.6	82.4
7	" "	25	126.8	1.31	9.7	237.4	87.5
8	" "	25	103.9	1.31	7.9	238.5	87.9
9	" "	25	118.0	1.31	9.0	246.2	90.8
11	" "	25	56.8	1.31	4.3	253.1	93.3
16	" "	25	40.9	1.31	3.1	279.1	102.9
22	" "	25	27.3	1.31	2.1	300.6	110.8
13	Feathers	25	50.5	1.01	5.0	261.6	96.4
24	"	25	20.0	1.01	2.0	320.9	118.4
15	Hair felt	25	242.7	1.31	18.5	277.4	102.3
19	" "	25	121.3	1.31	9.2	292.8	107.9
50	Air alone	25	.....	....	0.0	1301.7	479.9
14	Lamp black, "Golden Star," loose	25	95.0	1.70	5.6	266.5	98.3
18	" " compressed	25	415.0	1.70	24.4	286.5	105.6
25	Cork charcoal, fine	25	78.7	1.43	5.3	323.6	119.3
29	" " coarse	25	45.0	1.43	3.1	343.4	126.5

32	Pine charcoal	25	163.0	1.37	11.9	376.4	138.8
47	Anthracite coal	25	827.0	1.63	50.6	968.2	357.0
54	Plumbago	25	628.0	2.40	26.1	1922.5	708.8
27	Calcined magnesia, loose	25	76.0	3.26	2.3	335.2	123.6
28	“ “ crowded	25	160.0	3.26	4.9	340.1	125.4
48	“ “ compressed	25	931.0	3.26	28.5	1155.9	426.0
31	Carbonate magnesia, loose	25	132.0	2.21	6.0	370.9	136.6
33	“ “ crowded	25	207.0	2.21	9.4	386.7	142.6
35	“ “ compressed	25	333.0	2.21	15.0	416.5	153.6
34	Fossil meal, loose	25	147.0	2.44	6.0	393.4	145.1
37	“ “ crowded	25	273.0	2.44	11.2	425.8	157.0
46	Plymouth sand	25	991.0	2.78	35.6	861.0	317.5
52	Coarse sand	25	1439.0	2.72	52.9	1683.6	620.7
53	Fine “	25	1408.0	2.74	51.4	1689.7	623.0
42	Coarse Omahalite	25	491.0	2.62	18.7	777.5	286.6
43	Fine “	25	628.0	2.54	24.7	823.1	303.5
45	Pumice stone, finely ground	25	873.0	2.55	34.2	844.6	311.4
51	Asbestos	25	247.0	3.05	8.1	1328.6	489.9
38	Oxide of zinc, loose	25	483.0	5.48	8.8	466.0	171.8
49	“ “ compressed	25	1772.0	5.48	32.3	1163.8	429.1
40	Paris white—ground chalk	25	781.0	3.09	25.3	559.6	206.3
44	Plaster of Paris	25	964	2.62	36.8	839.2	309.4
41	Barium sulphate, flour	25	1792.0	4.70	38.1	728.6	268.6
55	Common salt	25	1032	2.15	48.0	1982.7	731.0

TABLE VII.

		Per cent. Solid Matter.	Kilo-Cent. Heat Units.	
50	Air space	0.0	1302	*a*
20	French cotton	0.9	299	*b*
23	Carded cotton	1.0	310	*c*
21	French cotton	1.9	299	*d*
17	Carded cotton	2.0	281	*e*
24	Feathers	2.0	321	*f*
22	Wool	2.1	301	*g*
27	Calcined magnesia	2.3	335	*h*
16	Wool	3.1	279	*i*
29	Cork charcoal, coarse	3.1	343	*j*
10	French cotton	4.1	248	*k*
11	Wool	4.3	253	*l*
28	Calcined magnesia	4.9	340	*m*
13	Feathers	5.0	262	*n*
25	Cork charcoal, fine	5.3	324	*o*
5	Wool	5.6	220	*p*
14	Lampblack	5.6	266	*q*
31	Carbonate magnesia	6.0	371	*r*
34	Fossil meal	6.0	393	*s*
6	Wool	6.9	224	*t*
8	Wool	7.9	238	*u*
51	Asbestos	8.1	1329	*v*
38	Zinc white	8.8	466	*w*
9	Wool	9.0	246	*x*
19	Hair felt	9.2	293	*y*
33	Carbonate magnesia	9.4	387	*z*
7	Wool	9.7	237	*A*
37	Fossil meal	11.2	426	*B*
32	Pine charcoal	11.9	376	*C*
35	Carbonate magnesia	15.0	416	*D*
15	Hair felt	18.5	277	*E*
42	Omahalite, coarse	18.7	777	*F*
18	Lampblack	24.4	286	*G*
43	Omahalite, fine	24.7	823	*H*
40	Chalk	25.3	560	*I*
54	Plumbago	26.1	1922	*J*
48	Calcined magnesia	28.5	1156	*K*
49	Zinc white	32.3	1164	*L*
45	Pumice stone	34.2	845	*M*
46	Plymouth sand	35.6	861	*N*
44	Plaster Paris	36.8	839	*O*
41	Barium sulphate	38.1	729	*P*
55	Common salt	48.0	1983	*Q*
47	Anthracite coal	50.6	968	*R*
53	Fine sand	51.4	1690	*S*
52	Coarse sand	52.9	1684	*T*

APPENDIX.

A few years since a very exhaustive investigation was made at the instance of the Boston Manufacturers' Mutual Fire Insurance Company, by Prof. John M. Ordway, now of Tulane University, New Orleans, but at that time of the Massachusetts Institute of Technology, upon the non-heat-conducting properties of various materials, some of which may be used for covering steam pipes and boilers; while others, owing to their liability either to become carbonized or to take fire, should not be directly applied to such use.

There are, however, other problems in preventing either the escape of heat or the ignition of wood-work by the impact of heat, for which purposes various substances are of use. It should not be assumed that because a given material is incombustible it is therefore *not* a quick conductor of heat. Neither should it be assumed that because a material is a quick conductor of heat it may *not* be made use of, in some cases, for protection against fire.

For instance, in the problem of making a fire-door. If the door be made of two thicknesses of solid wood at right angles to each other to prevent warping, this door may be encased in sheet-iron or tinned plates with the joints carefully locked, and it will become a good fire stop, although both the sheet-iron and the tin-plate are good conductors of heat. The reason of this is, that while the wood, which is in immediate contact with the metal, will be carbonized, yet even the sheets of hot metal, if thoroughly locked, and therefore thoroughly encasing the wood, keep out the oxygen; then, for want of sufficient air to ignite the carbonized wood, the door remains solid and strong for many hours. Thin plates of tinned iron or steel serve this purpose, where thick plates would warp or bend under heat so as to fail in keeping the door-way tightly closed. Iron doors and shutters are often worse than useless, owing to this tendency to warp or bend, opening a way for fire while obstructing the firemen; also because when heated they do not serve as a guard near which firemen may protect adjacent wood-work. Zinc, although frequently used, is worthless as a fire stop because of its very low melting point. If a door is tinned on one side only, it may be burned nearly as quickly as if there were no tin upon it, although it may not be ignited quite so soon.

In order that the relative merits of the different substances which are in use for preventing the escape of heat from boilers and steam pipes, or as substitutes for wire lathing and plastering, or for tin-plates in the protection of elevator shafts, or of wood-work nailed closely to walls, the following tables and extracts from a later report made by Professor Ordway are submitted. It will be observed that several of the incombustible materials are nearly as efficient as wool, cotton, and feathers, with which they may be compared in the following table. The materials which may be considered wholly free from the danger of being carbonized or ignited by slow contact with pipes or boilers are printed in roman type. Those which are more or less liable to be carbonized are printed in italics.

Professor Ordway's report is as follows: "Careful experiments have been made with various non-conductors, each used in a mass one inch thick, placed on a flat surface of iron kept heated by steam to three hundred and ten degrees Fahrenheit. The following table, with which the graphical lines correspond, gives the amount of heat transmitted per hour through each kind of non-conductor one inch thick, reckoned in pounds of water heated ten degrees Fahrenheit, the unit of area being one square foot of covering."

Substance 1 Inch Thick. Heat applied 310° F.	Pounds of Water Heated 10° F. per Hour, Through 1 Square Foot.	Solid Matter in 1 Square Foot 1 Inch Thick. Parts in 1000.	Air Included. Parts in 1000.
1. Loose Wool	*8.1*	*56*	*944*
2. Live Geese Feathers	*9.6*	*50*	*950*
3. Carded Cotton	*10.4*	*20*	*980*
4. Hair Felt	*10.3*	*185*	*815*
5. Loose Lamp-black	*9.8*	*56*	*944*
6. Compressed Lamp-black	*10.6*	*244*	*756*
7. Cork Charcoal	*11.9*	*53*	*947*
8. White Pine Charcoal	*13.9*	*119*	*881*
9. Anthracite Coal Powder	*35.7*	*506*	*494*
10. Loose Calcined Magnesia	12.4	23	977
11. Compressed Calcined Magnesia	42.6	285	715
12. Light Carbonate of Magnesia	13.7	60	940
13. Compressed Carbonate of Magnesia	15.4	150	850
14. Loose Fossil Meal	14.5	60	940
15. Crowded Fossil Meal	15.7	112	888
16. Ground Chalk (Paris White)	20.6	253	747
17. Dry Plaster of Paris	30.9	368	632
18. Fine Asbestos	49.0	81	919
19. Air Alone	48.0	0	1000
20. Sand	62.1	529	471

The first column of figures of results, therefore, gives the loss by the measure of pounds of water heated ten degrees. The second column gives the amount of solid matter in the mass one inch thick. The third column gives the amount or bulk of included or entrapped air. In the graphical table, the value of the non-conducting material is, therefore, in inverse proportion to the length of the line, the short lines showing but a small amount of transmitted heat; the long lines showing the larger amounts.

There are some mixtures of two materials which may be quite safe, although consisting in part of substances which may be carbonized. It must also be considered that a covering for a steam pipe or boiler should have some strength or elasticity, so that, when even put on loosely and holding a great deal of entrapped air, it may not be converted into a solid condition by the constant jar of the building, then becoming rather a quick conductor. This warning may be applied especially to what is called "slag wool," which consists of short, very fine threads of what may be considered in this report as a brittle kind of glass.

The substances given in the following table were actually tried as coverings for two-inch steam-pipe, but, for convenience of comparison, the results have been reduced by calculation to the same terms as in the foregoing table.

COVERING.	Pounds of Water Heated 10° F. per Hour, by 1 Sq. Ft.
21. Best Slag Wool	13.0
22. Paper	*14.0*
23. Blotting Paper wound tight	*21.0*
24. Asbestos Paper wound tight	*21.7*
25. Cork strips bound on	*14.6*
26. Straw Rope wound spirally	*18.0*
27. Loose Rice Chaff	*18.7*
28. Paste of Fossil Meal with Hair	16.7
29. Paste of Fossil Meal with Asbestos	22.0
30. Loose Bituminous Coal Ashes	21.0
31. Loose Anthracite Coal Ashes	27.0
32. Paste of Clay and Vegetable Fiber	30.9

Later experiments, not yet published, have given results for still air which differ little from those of Nos. 3, 4, and 6. In fact, the bulk of matter in the best non-conductors is relatively too small to have any specific effect, except to entrap the air and keep it stagnant. These substances keep the air still by virtue of the roughness of their fibers or particles. The asbestos of 18 had smooth

fibers, which could not prevent the air from moving about. Later trials with an asbestos of exceedingly fine fiber have made a somewhat better showing, but asbestos is really one of the poorest non-conductors. By reason of its fibrous character, it may be used advantageously to hold together other incombustible substances, but the less the better. Trials have been made of two samples of a "magnesia covering" consisting of carbonate of magnesia bonded with a small percentage of good asbestos fiber. One specimen transmitted heat which, reduced to the terms of the first of the above tables, would amount to 15 lbs.; the denser one gave 20 lbs. The former contained 250 thousandths of solid matter; the latter 396 thousandths.

Charcoal, lamp-black, and anthracite coal are virtually the same substance, and Nos. 5, 6, 7, 8, and 9 show that non-conducting power is determined far less by the substance itself than by its mechanical texture. In some cases when a greater quantity of a material is crowded into the same thickness the non-conducting virtue is somewhat increased, because the included air is thereby rendered more completely fixed. But if the same quantity is compressed so as to diminish its thickness, its efficiency is lessened; for the resistance to the transmission of heat is nearly—though by no means exactly—in proportion to the thickness of the non-conductor. Hence, though a great many layers of paper—as in No. 23—prove to be a tolerably good retainer of heat, one or two layers are of exceedingly little service. Any suitable substance which is used to prevent the escape of steam heat should not be less than an inch thick.

Any covering should be kept perfectly dry, for not only is water a good carrier of heat, but it has been found in our trials that still water conducts heat about eight times as rapidly as still air.

Relative Efficiency of Materials which are used to Diminish the Waste of Heat.

No.	Substance. One inch thick. Heat applied 310° F.	Pounds of water. Heated 10° Fahr. per hour, by transmission through one square foot.
1	*Loose wool*	*8.1*
2	*Live geese feathers*	*9.6*
3	*Carded cotton wool*	*10.4*
4	*Hair felt*	*10.3*
5	*Loose lamp-black*	*9.8*
6	*Compressed lamp-black*	*10.6*
7	*Cork charcoal*	*11.9*
8	*White pine charcoal*	*13.9*
9	*Anthracite coal powder*	*35.7*
10	Loose calcined magnesia	12.4
11	Compressed calcined magnesia	42.6
12	Light carbonate of magnesia	13.7
13	Compressed carbonate of magnesia	15.4
14	Loose fossil meal	14.5
15	Crowded fossil meal	15.7
16	Ground chalk (Paris white)	20.6
17	Dry plaster of Paris	30.9
18	Fine asbestos	49.0
19	Air alone	48.0
20	Sand	62.1
21	Best slag wool	13.0
22	*Paper*	*14.0*
23	*Blotting paper, wound tight*	*21.0*
24	*Asbestos paper, wound tight*	*21.7*
25	*Cork strips, bound on*	*14.6*
26	*Straw rope, wound spirally*	*18.0*
27	*Loose rice chaff*	*18.7*
28	Paste of fossil meal with hair	16.7
29	Paste of fossil meal with asbestos	22.0
30	Loose bituminous coal ashes	21.0
31	Loose anthracite coal ashes	27.0
32	Paste of clay and vegetable fibre	30.9

The loss is indicated by the length of the lines. Incombustible material designated in roman type; material which may be ignited or slowly carbonized indicated in italics.